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SITE AND EXTENT OF DIGESTION IN BEEF HEIFERS: INFLUENCE OF SORGHUM GRAIN VARIETY AND BLENDS OF HIGH MOISTURE SORGHUM AND DRY CORN GRAIN

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SITE AND EXTENT OF DIGESTION IN BEEF HEIFERS:

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CHAPTER I

INTRODUCTION

Declining water supplies in the Great Plains region and increased cost of irrigation should cause an increase in the use of sorghum grain as an energy source in cattle finishing operations. Sorghum grain is drought tolerant and requires less water under irrigation when compared to other common cereal grains such as corn. Sorghum has been discriminated against by many producers because of reduced feeding value when compared to corn (NRC, 1984). However, sorghum is often priced enough below corn to make total or partial sorghum diets economical. Discrimination against sorghum grain has also occurred because of the need for processing and the great variation that exists in endosperm color, berry size and berry hardness. In vitro studies with sorghum grain varieties indicate that some varieties of sorghum grain are more highly fermentable than others (Hibberd et al., 1982a). The advent of high moisture harvest and reconstitution may reduce the cost of sorghum processing; however, steam flaking remains the preferred processing method.

Limited work has been conducted looking at the effects of different sorghum varieties on site and extent of digestion (Hibberd et al., 1985). Hibberd et al. (1985) has suggested that sorghum grain variety may be responsible for altering site and extent of starch and protein digestion. Sorghum variety may also influence the efficiency of microbial protein production (Hibberd et al., 1985). The effects of sorghum varieties on site and extent of starch and protein digestion remain largely unknown, however, the potential exists to select varieties of increased nutritional value.

The effects of blending high moisture harvested sorghum grain and dry rolled corn on in vitro or in vivo nutrient digestion have not been studied. Associative effects may exist that make some combination of wet sorghum and dry corn optimal for starch and protein digestion. The ratio of high moisture harvested sorghum grain to dry rolled corn may influence site and extent of starch and protein digestion as well as the efficiency of microbial protein production in the rumen.

Two experiments were conducted and reported in this thesis, one utilizing four widely divergent sorghum grain varieties (waxy endosperm, bird resistant; normal endosperm, bird resistant; normal endosperm; waxy endosperm) and the second using five combinations of high moisture harvested sorghum grain and dry rolled corn (100% dry rolled corn; 75%:25%; 50%:50%; 25%:75%; 100% high moisture harvested sorghum). Sorghum varieties were studied to determine their effect on in vitro dry matter disappearance, in vitro gas production and site and extent of nutrient digestion in beef heifers. High moisture harvested sorghum grain and dry rolled corn blends were studied to determine the effect of the ratio of dry rolled corn to high moisture sorghum on in vitro gas production and the site and extent of starch and protein digestion and the efficiency of microbial protein production in beef heifers.

CHAPTER II

LITERATURE REVIEW

Environmental Effects on Chemical Composition of Sorghum Grains

Environmental condition play an important role in the composition of sorghum grain (Heller and Seiglinger, 1944; Hibberd et al., 1982a). Under dry conditions reduced yields are observed; however, the protein content of the grain is enhanced (Heller and Seiglinger, 1944; Miller et al., 1962). The essential amino acids are also dependent on the availability of moisture, tending to decrease in concentration as protein levels increase (Virupaksha and Sastry, 1968). Protein ranges from 5.9% to 18.2% between varieties (Miller et al., 1962; Virupaksha and Sastry, 1968) and individual varieties may show as high as 13 percentage unit changes in protein content from year to year (Hibberd et al., 1982a). Greater variation exist between than within sorghum varieties. Further work is needed to determine the factors controlling the chemical composition of sorghum grain. A greater understanding of the effects of the environment should enhance sorghum grain production while at the same time improve the nutrient characteristics of sorghum grain.

Effects of Sorghum Grain Characteristics on Digestibility

McCollough and Brent (1972) and Schake et al. (1976) suggest that sorghum grain is 5 to 10% less digestible than corn. Barley may also have greater feeding value for cattle than sorghum grain (Saba et al., 1964). Sorghum varieties; however, do exist that have a higher digestibiliy than corn (Samford et al., 1970; Miller et al., 1972).

McCollough and Brent (1972) have shown that endosperm type is related to nutrient digestibility of sorghum grain. Within eight sorghum hybrids tested, grains with white endosperm tended to have lower digestibilities than those with yellow endosperm. One bird resistant hybrid included in the study had greatly reduced crude protein and dry matter digestibilities. Miller et al. (1972) found the percent floury endosperm influenced digestibility. Sorghum varieties with greater than 75% floury endosperm had higher nylon bag dry matter digestibility (NBDMD) than those with less than 40% floury endosperm. Grains with brown and purple endosperms tended to have lower digestibilities regardless of floury endosperm content. However, grain with floury endosperm generally has a low density and test weight limiting its commercial usefulness (Sullins and Rooney, 1974). Sorghum varieties with waxy endosperm have higher in vitro dry matter disappearance (IVDMD) than varieties with normal endosperm (Hibberd et al., 1982a,b). In vivo studies conducted by Nishimuta et al. (1969) agree with these findings. Waxy starch may be more available due to the branched nature of amylopectin (French, 1973), or increased starch granule accessibility due to greater solubility of matrix protein, less amorphous protein matrix and less peripheral endosperm (Sullins and Rooney, 1974; Lichtenwalner et al., 1978).

Sorghum grain digestibility is decreased as berries become harder (Samford et al., 1970). Decreasing moisture, berry size and soil fertility may increase berry hardness. Large berries may be softer than small berries. The primary seed characteristic related to seed hardness; however, is endosperm type. Berries with floury endosperm are softer than berries with normal or waxy endosperms (Sullins and Rooney, 1974).

Seckinger and Wolf (1973) suggest protein to be the factor limiting sorghum starch digestibility. Higher protein sorghum grains are also given lower energy values by the beef cattle NRC (1984). The protein matrix surrounding the starch granule is extremely dense and insoluble in the peripheral endosperm of sorghum grain. Information is currently not available on more current sorghum grain hybrids concerning the relationship of protein and energy. NRC (1984) energy values for sorghum grains are; therefore, in great need of investigation.

Bird resistant sorghum varieties contain condensed tannins that give the grain an astringent taste making it less palatable and less digestible (Saba et al., 1972). Muind et al.(1981) treated bird resistant sorghum high in tannin with magadi soda to remove condensed tannins (40 to 57%) and noted increased in vitro organic matter, starch and protein digestion. However, soda treatment did not result in levels equal to low tannin non-bird resistant sorghum grain and low tannin grains were not influenced by soda treatment. This indicates that factors other than tannin influence digestion in vitro. Studies using rats reported by Muidi and Thomke (1981) are in agreement with in vitro experiments. On the other hand, bird resistant types with waxy endosperm have greater IVDMD than bird resistant types with normal endosperm (Hibberd et al., 1982a,b). The waxy condition may offer a method of overcoming the detrimental effects of the bird resistant characteristic on nutritive value. In vitro gas production (IVGP) studies conducted by Hibberd et al. (1982b), measuring the enzymatic availability of starch, demonstrate that waxy starch is more available than normal starch regardless of bird resistance. IVGP of bird resistant types with normal endosperm was depressed similar to the depression observed in IVDMD, suggesting that the factors that limit attack by rumen microbes may also limit enzymatic starch availability (Hibberd et al., 1982b). Other factors associated with the bird resistant characteristic may influence organic matter and protein digestion and need further investigation.

Diet composition may influence the digestibility of bird resistant sorghum grain in vitro and when fed to steers. White and Hembry (1978) fed all concentrate and concentrate with 20% rice straw diets and observed improved energy, nitrogen free extract and crude protein digestibilities in 20% rice straw diets containing bird resistant grain, while decreasing the digestibilities of rations containing bird susceptible grain. The source of rumen fluid for IVDMD had no effect on bird susceptible grain; however, bird resistant grain IVDMD increased by 8.7% when rumen fluid was obtained from steers fed 20% rice straw compared to fluid from steers receiving all concentrate diets. Improvements in digestibility with 20% roughage suggests a different microbial population may be present or different endproducts may result from fermentation of rice straw that decrease the detrimental effects of tannin (White and Hembry,1978). Further work is needed to determine if the improved digestibility of bird resistant sorghum grain associated with rice straw is in fact due to the straw or if the rumen microbial population adapts to high tannin levels. Increased levels of some types of roughage may slow or speed the rate that solids pass out of the rumen, thus, increasing the time for microbial destruction of condensed tannins in vivo. Reduced solid passage rate may also alter the microbial population of the rumen (Van Soest, 1982).

Effect of Stage of Maturity

Increasing energy costs have caused re-evaluation of sorghum processing methods requiring large amounts of energy, such as steam flaking. High moisture harvest and reconstitution of dried grain require less energy yet yield improvements in digestibility and performance similar to steam flaking (Hale and Prouty, 1980; Mies and Summers, 1980). The mechanisms responsible for improved daily gains and feed efficiency with high moisture grain feeding are not clearly understood. Harvesting grain at high moisture levels creates considerations unique to this processing method. If grain is harvested before maturity (completion of dry matter deposition) one would anticipate chemical composition to differ from mature grain and dry matter yield to be reduced. Maximum dry matter content generally occurs 39 days post pollination (Kersting et al., 1961) or when the sorghum berry contains 70% dry matter (Hibberd et al., 1983).

Protein content (%) appears to be maximal 3 to 6 days post pollination and decreased steadily from 18 to 24 days after pollination, thereafter, remaining relatively constant (Kersting et al., 1961). Hibberd (1982) reported protein content (%) of divergent varieties of sorghum grain decreased through 55 to 60% dry matter before plateauing. Bird resistant types may reach constant protein content (%) earlier (50 to 55% dry matter) than other varieties (Hibberd, 1982). Protein deposition expressed as g/berry or mg per 100 berries increases up to 30 to 42 days after pollination (Kersting et al., 1961). Similarly, Hibberd (1982) reported increasing protein deposition through 65 to 70% dry matter. Data obtained by Misra et al. (1975) with corn demonstrates the same trends in protein content and deposition post pollination. Increasing starch biosynthesis and storage results in dilution of the protein content (Kersting et al., 1961; Misra et al., 1975; Hibberd, 1982). Nitrogen distribution, which may effect starch availability, changes with maturity of corn and sorghum. Laundry and Moureaux (1970) fractionated plant proteins based on solubility into five fractions. Fraction I contains albumins and globulins (salt soluble proteins). Fractions II and III contain kaferin or kaferin like proteins (alcohol soluble protein). Fractions IV and V contain glutelin or glutelin like proteins (borate buffer soluble proteins). Fourteen days post pollination, the albumin-globulin fraction predominates (57 to 83% total nitrogen). As the kernel matures greater amounts of matrix protein (glutelin) are deposited along with kaferin, the storage protein in sorghum grain. Protein quality of sorghum grain decreases with maturity (Deyoe et al., 1970). Decreasing protein quality of corn was reported by Thornton et al.(1969a). Kaferin is low in lysine; therefore, increasing deposition of kaferin is probably the cause of decreased protein quality. The proportion of highly soluble protein (albumin-globulin) decreases with maturity in corn (Misra et al., 1975). Hibberd (1982) reported decreasing salt (NaCl) soluble protein, presumed to be albumin and globulin, with maturity in sorghum grain. Varieties studied showed similar decreases; however, bird resistant types tended to have lower levels of salt soluble protein at all stages of maturity (Hibberd, 1982).

Starch deposition in sorghum grain begins about 7 days after pollination and is nearly completed by 25 days post pollination (Kersting et al., 1961). When maximum dry weight is obtained starch may comprise 60 to 75% of the dry matter. A reduction in starch content does occur past the point of maximum dry weight, indicating that respiration in the sorghum plant continues after physiological maturity has been obtained (Kersting et al., 1961). Starch content (%) and deposition (g/berry) of developing sorghum grain parallel each other as the maturation process takes place (Kersting et al., 1961). Thornton et al. (1969a) noted increasing starch content and deposition in corn grain as maturation proceeded. The type of starch, amylose or amylopectin, changes as maturation occurs. Boyer et al. (1976) reported that as corn matured starch granule size and amylose content increased. Large starch granule size at maturity suggests that granules may grow during maturation.

Tannin content of bird resistant sorghum increases by approximately 29% between the milk and dough stages. Assaible condensed tannin content decreases dramatically, as much as 80% in many sorghum varieties as sorghum continues to mature (Davis and Hoseney, 1979b; Price et al., 1979b; Bullard et al., 1981; Glennie, 1981; Glennie et al., 1981; Hibberd, 1982). Glennie (1981) fractionated polyphenols by molecular weight and solubility in water (fraction I), acid-methanol (fraction II) and methanol (fraction III). Fraction I polyphenols are of low molecular weight, do no bind to proteins, and therefore, are not classified as true tannins. Fractions II and III are high molecular weight, condensed tannins that have protein binding capacity. McLeod (1974) suggested that polymerization of condensed tannins increases as maturity occurres. Glennie (1981) conducted studies showing that fraction I reached a peak during the milk stage while at the same stage fractions II and III (condensed tannins) were at minimal levels (near zero). Five days later at the soft dough stage fractions I was at a minimal level while fractions II and III had reached near maximal levels. The relationship of fractions I, II and III suggests that fraction I is polymerized during maturation to form fractions II and III.

Decreases in tannin after the hard dough stage are probably not due to actual loss of tannin, but to a change in solubility or chemical reactivity so that the tannins are no longer detectable by the assay procedure. Decreased solubility could result from formation of an insoluble complex between tannin and some other cellular component (possibly protein) or an increase in the degree of polymerization. The vanillin assay may be particularly susceptible to under estimation of tannin content due to increased polymerization (Price et al., 1979b; Glennie 1981). High molecular weight tannins may have a decreased capacity to bind protein (Glennie 1981). Therefore, early harvest of some bird resistant sorghum grains may increase the potential for protein binding in the digestive tract. Tannins create a unique problem for sorghum grain researchers that deserves further study.

High Moisture Harvest of Sorghum Grain

Sorghum grain usually does not support the degree of animal performance (rate of gain and feed efficiency) one would predict from gross composition. Many grain processing methods have been developed in an attempt to alter the protein matrix or starch granule of sorghum grain (McNeill et al., 1975; Walker and Lichtenwalner, 1977). They include grinding, steaming flaking (Hale et al., 1966), micronization (Croka and Wagner, 1975a,b), reconstitution (Totusek et al., 1967) and high moisture harvesting (White et al., 1969). Grinding produces the smallest improvements in digestibility and animal performance. Steam flaking and micronization are limited by the energy input required by each process. Reconstitution and high moisture harvest produce improvements in digestibility and animal performance nearly equal or greater than steam processing with greatly reduced energy requirements (Newsom et al., 1968; White et al., 1969).

High moisture harvest of sorghum grain causes several special considerations. Harvest would normally occur at no greater moisture content than 30 to 35%, if the grain is not mature at this point a penalty may be paid in dry matter yield. If sorghum grain nutrient deposition and physiological maturation is similar to corn, one would predict only slightly reduced nutritional value of immature sorghum grain (Thorton et al., 1969b). A discussion of changes associated with the maturation process is contained elsewhere in this manuscript.

The level of moisture present in wet sorghum grain (reconstituted and harvested) may greatly influence the improvements in digestibility and efficiency of dry matter utilization. Neuhaus and

Totusek (1971) demonstrated that IVDMD increased as moisture levels increased from 13 to 35%. IVDMD response tended to be small between 13 and 22% and plateau or decrease slightly between 26 and 30% moisture, but increase again at 35% moisture. Seventy percent dry matter is generally recognized as the optimal point to harvest high moisture sorghum.

Improvements in animal performance and nutrient digestibility obtained with high moisture harvested corn are similar but smaller in magnitude than those observed with high moisture sorghum grain. More work has been done with corn; therefore, inferences may be beneficial. High moisture harvested corn containing 20 to 24% moisture is not as well utilized as either dry corn or corn containing greater than 27% moisture (Gill et al., 1982). Danley and Vetter (1974) compared the in vitro utilization of corn harvested at 16, 18 and 22% moisture. Corn that was not ensiled showed increased dry matter, total carbohydrate and nitrogen disappearance as moisture level increased; however, when grain was ensiled a decrease in all areas was noted at the 22% moisture level. Teeter et al. (1979) reported corn harvested at 20% moisture resulted in decreased average daily gain and feed efficiency (feed/gain) when fed to steers. Dry matter digestibility was similar to corn at 14% moisture (70.0 versus 70.1%), but greatly less than corn at 27% moisture (70.1 versus 74.5%). Protein digestibility was lowest for dry corn (14% moisture, 52.1%), highest for corn with 27% moisture (65.3%) and intermediate for corn with 20% moisture (56.5%). Presumably, poor digestibility of corn or sorghum ensiled at medium moisture levels (22% to 26%) results from denaturation of protein, due to heating, or butyric acid fermentation.

Aguirre et al. (1984b) demonstrated that the moisture content of corn may alter site and extent of nutrient digestion in steers. Corn at 25% moisture had less total tract and ruminal starch digestion. Starch digestion in the small intestine was enhanced by increasing moisture level. True ruminal nitrogen digestion was lowest at 20 and 25% moisture and highest at 15 and 35% with 30% moisture corn being intermediate. Alterations in solid passage rate and decreased protein availability may explain these findings. Improvements obtained with reconstitution and high moisture harvest of sorghum grain probably do not occur through the same mechanism. However, both are dependent on moisture level and the end result at a given moisture level is usually quite comparable (Newsom et al., 1968; White et al., 1969; Riggs and McGinty, 1970).

Some interest has been expressed in blending high moisture and dry grains in an attempt to maximize both ruminal fermentation and bypass. Teeter et al. (1979) blended high moisture corn (27%) and dry corn (14%) in a 50% HMC; 50% dry corn mixture. Cattle performed better on the blend than on either high moisture or dry corn. Average daily gain and feed efficiency were enhanced by 2.0% and 1.2% respectively, over high moisture corn. Dry matter digestibility was not increased for the blend when compared to dry corn; however, protein digestion was greater for the blend than dry corn (60.4 versus 52.1%) and slightly less than high moisture corn (60.4 versus 65.3%). Starch disappearance was similar for the blend and high moisture corn and greater than corn of 20% moisture. More recently Brandt et al. (1984) compared animal performance and starch digestion of the following corn blends: 100% high moisture corn (HMC),67% HMC: 33% dry rolled corn (DRC), 33% HMC: 76% DRC, and 100%

DRC. Over a 108 day feeding period similar average daily gains were achieved, but gain/feed tended to increase as HMC replaced DRC. Starch digestion was greatest for 100% HMC and decreased with more DRC.

No work has been conducted blending high moisture sorghum grain with dry rolled corn. Further work is needed to determine the effects of blending dry and high moisture grains on animal performance and digestibility. Associative effects may exist between dry and high moisture grains; however, currently the price of grains dictates the ratio between high moisture and dry grains in a blend. Information about performance and digestibility would allow the producer to consider associative effects in combination with grain prices to determine the specific ratio of dry to high moisture grain.

Originally it was believed that improvements in sorghum grain digestibilitiy associated with processing were due to gelatinization of the starch granules; however, high moisture harvest of sorghum grain results in increased digestibility, yet no gelatinization of starch granules occurs. Therefore, factors other than starch gelatinization must cause increases in digestibility and utilization of processed sorghum grain starch (McNeill et al., 1975).

Effectiveness of a processing method appears to depend upon the solubilization of the protein matrix encapsulating starch granules (McNeill et al., 1975). Walker and Lichtenwalner (1977) reported that reconstitution tended to increase the percent soluble protein (Fraction I) found in sorghum grain. Fraction III protein was also increased by reconstitution. Reconstitution decreases the digestibility of fractions II and IV while increasing the digestibility of fractions III and I. Lichtenwalner et al. (1978) attributed a portion of the observed improvement in starch digestibility and availability of waxy sorghum grain to an increased solubility of the protein matrix encapsulating the starch granule. Reconstitution and possibly high moisture harvest of sorghum grain may result in extensive hydration of the protein matrix making the matrix more susceptible to mechanical disintegration resulting in smaller particle size and thereby making the starch granule more accessible to enzymatic and microbial attack (McNeill et al., 1975). Prigge et al. (1976a) suggests increased protein solubility of corn during fermentation may be attributed to chemical and physical factors including; increased active acidity, possibly effecting microbial protease activity (Burgur, 1966), osomolarity and hypertonicity. Fermentation itself may not be the mechanism that increases protein solubility (Prigge et al., 1976a).

Anaerobic storage and fermentation may be responsible in part for increased value of bird resistant sorghum grains due to partial destruction of tannin (Hibberd, 1982). Reichert et al. (1980) proposed that fermentation may deactivate tannins by acid catalyzed polymerization resulting in extremely high molecular weight, non-soluble, olegomeric tannin polymers that have a reduced capacity to bind protein. Studies looking specifically at the destruction of condensed tannins during anaerobic fermentation are limited. Elucidation of the mechanism responsible for tannin deactivation may allow manipulation of the process to enhance tannin removal from bird resistant sorghum grains.

Factors Effecting Site and Extent of Starch and Protein Digestion

The need for more efficient production has forced the beef cattle industry to shift from forage to concentrate feeding. Grain processing, feeding regimes and feed additives have been developed to further enhance the efficiency of production by increasing the availability and utilization of the cereal grain portion of rations. A great deal of research has been conducted to determine the effect of altering the site of cereal grain starch and protein digestion on total tract utilization. Interest in the effect of starch digestion in the small intestine on animal performance has been great. Theoretical calculations with concentrates fed to non-ruminant lambs demonstrate the potential for more efficient production due to reduced energy losses associated with fermentation (Black, 1971).

The small intestine has a relatively large capacity to digest starch; however, an upper limit is present (Karr et al., 1966; Orskov et al., 1969). Waldo (1973) suggested the upper limit to be 7.7g of starch or 8.6g glucose per kilogram of metabolic weight (kg body wt.$^{.75}$). Escape of starch from ruminal fermentation may play an important role in meeting the glucose requirements of high producing animals (Armstrong and Smithard, 1979). Greater glucose absorption from the small intestine should allow propionic acid and glucogenic amino acids produced in the rumen to be utilized for functions other than gluconeogenesis (Sutton, 1971).

The level of starch intake and rate of passage play an important role in determining the amount of starch reaching both the small and large intestines. Karr et al. (1966) have reported increasing starch intake in steers from 1002 to 2684 g/day, to increase starch recovery at the abomasum (357 to 982 g/day). Similar increases in starch reaching the ileum (26 to 358 g/day) and feces (12 to 62 g/day) were noted. DeGregorio et al. (1982) found a similar increase in starch reaching the small and large intestines of lambs as corn levels increased. Differences in rates of passage of particles from the rumen have been suggested as the cause of increasing starch bypass associated with higher starch intakes by Orskov et al. (1969).

Starch bypass of the rumen and large intestinal starch fermentation may substantially change the nitrogen and essential amino acid status of an animal. Increasing starch bypass of the rumen should reduce the amount of available energy for microbial use in protein synthesis (Orskov, 1977). A decrease in microbial protein synthesis caused by reduced energy availability would be expected to result in reduced amounts of protein passing to the abomasum, unless dietary protein escaped fermentation at an equal rate to starch (Orskov et al., 1969; Sutton, 1971; Waldo, 1973). Reduced protein synthesis would furthermore be expected to alter the amino acid pattern of the protein absorbed from the small intestine (Black, 1971). Zinn and Owens (1983b) reported increasing feed intake of a 63% dry rolled corn diet resulted in an increased flow of nitrogen, non ammonia nitrogen, microbial nitrogen and feed nitrogen to the small intestine. Perhaps increasing feed intake results in enhanced microbial efficiency (Zinn and Owens, 1982b). Interestingly, in the same study ruminal starch digestion increased with feed intake (79.6 to 91.0%).

Large intestinal starch fermentation may results in the irreversible loss of microbial protein (Orskov et al., 1969; Armstrong and Smithard, 1979) because the microbial protein synthesized is excreted in the feces. Orskov (1982) reported total nitrogen excreted in the feces to be greater than that passing the terminal ileum when large amounts of starch fermentation occurred in the large intestine. The most efficient use of starch and protein by the ruminant appears to occur when degradation occurs prior to the ileum. Starch and protein bypass to the small intestine is advantageous if the amount of starch does not exceed the capacity of the small intestine and the ruminal nitrogen requirements for efficient fermentation are met.

Factors Effecting Ruminal Starch and Protein Fermentation

Level of feed intake, starch intake and method of processing are factors that alter ruminal starch and protein digestion. Dietary factors probably exert their influence by altering rumen environment (ruminal pH, ammonia levels and passage rate from the rumen).

The level of feed intake and source of roughage may cloud many estimates of ruminal starch digestion. Decreased ruminal starch digestion was noted by Galyean et al. (1979) as intake was increased from 1 (94.5%) to 2 (89.6%) times maintenance. Roughage was supplied by cottonseed hulls and dehydrated alfalfa (50:50). Liquid dilution rate and out flow rate of the rumen were increased by intake (Galyean et al., 1979). Weller and Gray (1953) suggested that a large portion (85 to 93%) of the starch present in the rumen is found in the liquid portion of the contents. Zinn and Owens (1980) noted a decrease in ruminal starch digestion as intake was increased from 1.5 (79.1%) to 2.0 (62.3) percent of body weight. Starch digestion in the rumen was increased in a study conducted by Zinn and Owens in 1983(a) as feed intake increased from 1.2 (79.6%) to 2.1 (91.0) percent of body weight. The roughage source present in the diet was cottonseed hulls. Hulls may result in decreased rumination as compared to a larger particle sized roughage source. Reduced rumination would result in reduced salivary flow; therefore, lower ruminal pH and possibly increased starch digestion in the rumen (Goetsch et al., 1983). Zinn and Owens (1982a) reported ruminal protein digestion decreased with increasing feed intake. A similar depression in ruminal protein digestion was reported by Zinn and Owens (1980).

Processing of cereal grains may influence ruminal starch digestion to a greater degree than other factors presented. Galyean et al. (1976) compared starch digestion in steers fed corn rations processed by dry rolling, steam flaking, high moisture harvested-ground prior to ensiling and high moisture harvested whole corn treated with propionic acid prior to ensiling. Ground high moisture harvested corn had the greatest ruminal starch digestibility (89.3) followed by steam flaking (82.9), dry rolling (77.8) and acid treatment (62.8%). McNeill et al. (1971) compared dry rolled, steam flaked, reconstituted and micronized sorghum grain. Steam flaking resulted in the greatest increase in ruminal starch digestion as compared to dry rolled grain (82.3 versus 42.2%). Reconstitution resulted in an intermediate ruminal starch digestion (66.2%) while micronization resulted in only a small increase over dry rolled grain (43.4 versus 42.2%). Hibberd et al. (1985) reported increased ruminal starch digestion associated with reconstitution of sorghum grain. Effects noted for high moisture grains maybe related to extensive solubilization of protein while steam flaking may increase ruminal starch digestion through gelatinization of starch granules (Galyean et al., 1976).

Several researchers have investigated the effects of level of roughage on starch digestion. Karr et al. (1966) reported starch digestion in the rumen to decrease by 15.2 % as the level of ground corn increased and ground alfalfa decreased. Other researchers using different roughage sources have reported no or extremely small depressions in starch digestion as the level of roughage was decreased (Cole et al., 1976a; Russell et al., 1981). Studies conducted by Zinn and Owens (1980) using prairie hay as a roughage source support the findings of Karr et al. (1966). Using corn base diets ruminal starch digestibility was increased by 18 percent as the level of roughage was increased from 20 to 40% of the ration dry matter.

Increasing roughage levels should cause an increase in liquid passage rate from the rumen. Small particles could be carried out with the liquid phase of the rumen contents (Van Soest 1982). Association of starch particles with the solid or liquid phase of the rumen contents may depend on roughage source as well as the size of grain particles. Roughages that cause greater rumination and salivary flow to the rumen may result in decreased starch digestion due to increasing ruminal pH (Goetsch et al., 1983).

Limited work has been conducted to determine the effects of different roughage sources on ruminal starch digestion. Goetsch et al. (1984a) investigated the effect of roughage sources for dry rolled sorghum diets. Starch digestion in the rumen tended to be higher when cottonseed hulls were the roughage or when no roughage was provided (100% sorghum). Particulate passage rate was negatively correlated (r=

-.55) to ruminal starch digestion and greatest for alfalfa (4.1%/hour). Fluid dilution rate (%/hour) was also greatest with alfalfa (8.0%). Goetsch and Owens (1984) compared 7% cottonseed hulls with 14 and 21% whole shelled corn in rolled sorghum grain based diets fed to steers. Ruminal starch digestion was greatest for rations containing 21% whole shelled corn (79.6%) followed by 7% cottonseed hulls (75.4%) and 14% whole shelled corn (70.0%). Further study is needed to determine the interactions of roughage source, starch source and ruminal parameters.

Sorghum variety may greatly influence expected ruminal digestion. Varietal differences in starch digestion have been indicated in vitro by Hibberd et al. (1982b) and in vivo by Hibberd (1982) and Streeter et al. (1984). Continued research into varietal differences with sorghum may yield information useful in the selection of more digestible varieties.

The protein supply to the rumen is interrelated to the microbes ability to utilize energy. Many of the same factors that effect starch digestion and passage from the rumen also influence ruminal protein degradation and bypass. Ammonia, derived from feed protein or NPN, is the main nitrogen source used in bacterial protein synthesis. Ruminal ammonia levels can greatly effect ruminal digestion (Mehrez and Orskov 1976). Satter and Slyter (1974) reported a minimum of 5 mg of ammonia nitrogen per deciliter to cause maximal microbial production. Weakley (1983) suggested higher values may be needed to obtain maximal organic matter digestion (5 to 10 mg/dl). Still higher values have been reported in sheep for maximal organic matter digestion (Mehrez and Orskov, 1976).

Ruminal pH may have many effects on digestion as mentioned earlier. Solubility of protein present in the rumen can be altered by ruminal pH (Waldo and Goering, 1979). Differences in protein solubility have been suggested to be the main factor limiting protein degradation in the rumen. Many attempts have been made to equate protein solubility in mineral buffers to ruminal protein degradation (Wohlt et al., 1973; Waldo and Goering, 1979); however, little success has been achieved. Mahadevan et al. (1980) has suggested that solubility or insolubility by itself does a poor job of explaining ruminal differences. However, structural characteristics and the presents of disulfide bridges appear to play an important role in limiting protein degradation. The source of dietary protein is related to ruminal degradation and bypass probably through differences in solubility, cross linking and structure of the protein (Orskov et al., 1971; Hume, 1974; Hembrey et al., 1975; Arambel and Coon, 1981).

Decreasing ruminal pH may also decrease the prevalence of proteolytic organisms. Bacteria isolated from an in vitro system at a pH below 6 (5.5 to 5) have reduced protease and deaminase activities (Erfle et al., 1982). Processing of grains may also alter protein solubility through denaturation or pH changes associated with ensiling. Processed protein utilization may be enhanced due to both protein and non protein factors such as ruminal dilution rate (Potter et al., 1971; Prigge et al., 1978; Aguirre et al., 1984a).

Ruminal protein digestion is also influenced by levels of protein and feed intake. Zinn and Owens (1981) observed a 52% increase in ruminal bypass of feed nitrogen as feed intake was increased from 1.6 to 2.2% of body weight. The response to increasing feed intake was curvilinear with the greatest increase occurring between 1.8 and 2.0% of body weight. Increasing bypass with feed intake adds strength to the use of protein solubility as a measure of ruminal protein digestion. As feed intake increases ruminal dilution rate should increase, reducing the time allowed for protein digestion (Zinn and Owens, 1983a). Linear responses of protein reaching the duodenum to increasing feed intake (Zinn and Owens, 1983a) and protein level (Laughren and Young, 1979) have been reported.

Roughage level influences protein digestion and ruminal retention time. Generally ruminal digestion of natural protein is greater when fed with a high roughage than a high concentrate diet (Zinn and Owens, 1983b). Ganev et al. (1979) reported disappearance of protein from nylon bags suspended in the rumen to be greater when sheep received dried grass than whole barley diets. Outflow rate was also greatest for those sheep receiving dried grass and increased with feed intake.

Cole et al. (1976b) suggested that increasing roughage level may cause greater nitrogen recycling as a result of increased salivation. Extensive nitrogen recycling would cause greater amounts of nitrogen to flow to the duodenum (Nolan et al., 1973). The rate of transfer of endogenous urea to the rumen appears to be associated with the concentration of ruminal ammonia, plasma urea and the amount of organic matter digested in the rumen. Clearance of urea to the rumen may be enhanced in both sheep and cattle by the addition of grain to the diet (Kennedy and Milligan, 1980).

Barry and Manley (1984) have reported increased nitrogen recycling associated with depressed ruminal organic matter digestion caused by tannins in forages. Hibberd et al. (1985) reported nitrogen reaching the duodenum exceeded nitrogen intake when bird resistant sorghum diets were fed to steers; however, corrected ruminal organic matter digestion was not depressed. The relationship between depressed organic matter fermentation associated with high tannin feedstuffs and increased nitrogen flow to the duodenum is in need of investigation.

Starch and protein supply to the rumen may alter the composition of bacteria. Rumen bacteria under certain conditions can accumulate intracellular polysaccharides (McAllen and Smith, 1974). Data obtained by McAllen and Smith (1977 and 1976) indicate that starch diets lead to prolonged periods of bacterial polysaccharide accumulation as compared to diets containing greater amounts of soluble sugar when nitrogen is limiting. Results obtained by Bergen et al. (1968) suggest that bacterial protein composition, amino acid composition and digestibility are not affected by diet. Further study is needed to determine the effects of bacterial polysaccharide accumulation on efficiency of microbial protein synthesis and starch digestion in the small intestine. A portion of the observed, lower than expected digestion of cereal grain starch in the small intestine may be due to bacterial polysaccharides.

Condensed tannin present in bird resistant sorghum grains may depress ruminal starch digestion. In vitro studies have shown that dry matter disappearance of non-bird resistant varieties is depressed by the addition of the testa layer (contains condensed tannins) from bird resistant sorghum grain varieties (Saba et al., 1972). Sorghum grain high in tannin has been reported to have reduced IVDMD by several researchers (Cummins 1971; Saba et al., 1972; Hibberd 1982). In vivo reports exist suggesting that starch digestion in the rumen is enhanced by the bird resistant characteristic (Hibberd et al., 1985; Streeter et al., 1984). Tannins could alter starch digestion in the rumen by complexing with microbial enzymes (Lyford et al., 1967) and starch

(Davis and Hoseney, 1979a). Davis and Hoseney (1979a) showed that two fractions may exist in isolated tannins. Fraction one is an inhibitory fraction that is adsorbed by starch. The second fraction is also inhibitory to starch digestion, but is not adsorbed by starch. Microbial growth maybe inhibited by condensed tannins; thereby, limiting starch digestion. Some organisms are sensitive to polyphenols while others show little response (Singh and Arora, 1980; Benson et al., 1984). The rumen may have the ability to overcome the detrimental effects of tannins depending on the sorghum variety and probably the presence of specific tannins (White and Hembry, 1978; Hibberd, 1982; Streeter et al., 1984).

Condensed tannins have been shown to interrupt microbial protein synthesis, deamination of amino acids and proteolysis in an artificial rumen (Tagari et al., 1965; Singh and Arora, 1980). Depression of cellulose and hemicellulose digestion have been associated with forage condensed tannins (Singh and Arora, 1980); however, Tagari et al. (1965) determined that depression of cellulose and hemicellulose digestion may have been caused by high levels of sugar rather than tannins. Barry and Manley (1984) reported forage tannins depressed hemicellulose and soluble carbohydrate digestion in the rumen, but not cellulose.

Bird resistant sorghum varieties have altered protein quality due to differences in fractional protein composition (Chibber et al., 1978; Guiragossian et al., 1978). Chibber et al. (1978) concluded that condensed tannins present in sorghum grain bind preferentially to the kaferin protein fraction (fraction II, alcohol soluble) causing the complex to behave like glutelin protein (fraction IV, borate buffer soluble). Hewitt and Ford (1982) reported alteration of amino acid digestion caused by legume tannin; however, all amino acid were not effected in an equal manner. Differences in amino acid response may be the result of fractional protein characteristics of specific varieties (Chibber et al., 1978).

Tannins are powerful reducing agents in alkaline solutions and are capable of reacting with amino and sulfhyral groups. Tannins may also form weak reversible associations with protein and cellulose. Because the associations are reversible it is possible to recover proteins from tannin by using substrates to which tannins bind more strongly than protein. Caffeine, urea, polyvinylpyrrolidone and polyethyleneglycol have been used successfully (McLoad, 1974). Use of tannins to protect protein from ruminal degradation has been explored by Driedger and Harfield (1972). The presents of condensed tannins in feeds may cause a reduction of feed intake while increasing the non-ammonia nitrogen supply to the duodenum (Barry and Duncan, 1984; Barry and Manley, 1984; Hibberd et al., 1985). Increased nitrogen flow to the duodenum may be caused by an increase in nitrogen recycling (Barry and Manley, 1984; Hibberd et al., 1985).

A greater understanding of the effects of condensed tannin on ruminal starch and protein digestion is extremely important to improve the selection of sorghum varieties. Undoubtedly varieties differ in the composition of their tannin fraction. Such differences would result in unequal enzyme binding capacities, substrate complexing and microbial inhibition.

Intestinal Starch and Protein Digestion

Starch digestion in the intestines is influenced by many of the same factors influencing ruminal digestion. Levels of feed and starch intake as well as grain processing may have the greatest effects on digestion. Increases in the rate of passage through the intestines could decrease the time allowed for digestion in a manner similar to ruminal digestion. The specific sorghum grain variety type appears to change digestion in a manner vary similar to those alterations observed in the rumen.

Ruminal starch digestion is decreased as feed and starch intake is increased; therefore, the amount of starch reaching the small intestine increases (Karr et al., 1966; Nicholson and Sutton, 1969; Galyean et al., 1979; Zinn and Owens, 1980; Russell et al., 1981). Increasing the amount of starch reaching the small intestine appears to depress small intestinal digestion (Zinn and Owens, 1980) expressed a percent of starch entering. The rate starch passes from the small intestine may increase, reducing the time for digestion to occur.

Amylase, maltase and isomaltase have been implicated by Armstrong and Smithard (1979) as enzymes potentially limiting starch digestion in the small intestine of ruminants. Concentrate feeding may reduce the pH of the small intestine to a suboptimal level for amylase activity, or an inadequate amount of amylase maybe secreted into the small intestine (Armstrong and Smithard, 1979). Recent work conducted by Remillard and Johnson (1984) suggests that starch hydrolysis in the small intestine of feedlot cattle is not limited by insufficient amylase secretion or depressed pH.

When feed or starch intake is increased large intestinal fermentation should become an important consideration (Karr et al., 1966; Russell et al., 1981; DeGregorio et al.,1982). Early studies attempting to quantify intestinal digestion of starch did not distinguish between digestion in the small and large intestines. Work conducted by Hibberd (1982) has shown that the large intestine may compensate for poor starch digestion in the rumen and small intestine. The large intestine appears to have great variation in its ability to digest starch; however, little work has been conducted looking directly at starch digestion in the large intestine. Galyean et al. (1979) observed the amount of starch in the feces increased as feed intake increased. Starch digestion in the large intestine, expressed as a percent of entry, decreases 20 percentage units as feed intake increased from 1.5 to 2.0% of body weight in a study by Zinn and Owens (1980). Grams of starch excreted also increased (10.6g to 63.0g) as feed intake increased. Orskov et al. (1970) infused starch into the large intestine of sheep and found the large intestine to have a limited capacity to digest starch. Starch in excess of 138g/day reaching the large intestine appeared in the feces. Goetsch and Owens (1984) infused soluble starch into the ileum of steers and noted an increase in hindgut passage rate, suggesting less time allowed for fermentation to occur.

Effective grain processing methods make starch more susceptible to ruminal and small intestinal digestion; however, because ruminal fermentation occurs prior to the small intestine reduced amounts of starch generally reach the small intestine (Cole et al., 1976a; Galyean et al., 1976; Hibberd, 1982; Hinman and Johnson, 1974a,b; McNeill et al., 1971; Osman et al., 1970). McNeill et al. (1971) reported post ruminal sorghum starch digestion to be enhanced by steam flaking (98.42%), reconstitution (98.42%) and micronization (95.0%) over dry grinding (94.42%). Although the above study did not distinguish between the large and small intestines, ruminal data would indicate that the capacity of the small intestine was probably not exceeded; therefore, processing should decrease the amount of starch fermented in the large intestine.

Limited information is available looking specifically at the effects of grain processing on large intestinal starch digestion, as a percent of intake or percent of entry. Hibberd (1982) compared site and extent of nutrient digestion for dry rolled and reconstituted sorghum grain. Small intestinal starch digestion, as a percent of entry was increased by reconstitution for the two varieties studied; however, large intestinal starch digestion as a percent of entry was slightly decreased due to reconstitution.

Great varietal differences do exist between sorghum varieties in ruminal starch digestion due to a variety of factors mentioned earlier. Undoubtedly many of the factors that limit ruminal starch digestion also limit enzymatic digestion in the small intestine. Sullins and Rooney (1974) conducted microscopic evaluation of sorghum lines differing in endosperm characteristics revealing that waxy sorghum starch may be more susceptible to enzymatic attack because of less peripheral endosperm. Harbers and Davis (1974) reported that amylase enzymes can diffuse through at least one cell wall layer and attack underlying starch granules. Some of the cell wall structures covering starch granules appear to be removed in the large intestine making underlying starch accessible to bacterial amylase enzymes. The protein matrix of waxy varieties may also be more soluble (Walker and Lichtenwalner, 1977); therefore, more susceptible to enzymatic degradation (Sullins and Rooney, 1974).

The digestion of protein or nitrogen in the small intestine appears to be extremely constant considering the supply of nitrogen consists of three very different protein supplies(microbial, residual feed and endogenous nitrogen). Zinn and Owens (1982a) reported small intestinal nitrogen digestion to be closely grouped around 69% (+- 3%). Hibberd (1982) reported that sorghum grain variety altered ($P<.05$) nitrogen disappearance in the small intestine. Hibberd (1982) reported that reconstitution of sorghum grain varieties increased nitrogen disappearance in the small intestine .

Zinn and Owens (1982b) summarized several studies involving pure cultures and bacteria isolated from the rumen and suggested a great range in apparent post ruminal bacterial nitrogen digestibility due to large intestinal fermentation associated with diet type and feed intake. Potter et al. (1971) demonstrated that true post ruminal digestion of total nitrogen in steers fed processed sorghum grain differed very little, even though the composition (microbial versus feed) of nitrogen differed greatly between processing methods. The protein source in concentrate diets may influence nitrogen digestion in the small intestine (Zinn and Owens, 1983b). Zinn and Owens (1981 and 1983a) demonstrated that increasing feed intake from 1.2 to 2.2% of body weight linearly increased nitrogen disappearance in the small intestine. Increases associated with feed and starch intakes may be caused by faster rumen turnover resulting in greater amounts of soluble, readily degradable protein reaching the small intestine.

Nitrogen degradation and absorption in the large intestine appears to be largely dependent on the amount of starch available for fermentation. Total tract apparent nitrogen digestibility maybe decreased by starch fermentation in the large intestine, due to microbial trapping of undegraded enzymes from the small intestine and of urea recycled from the blood to the large intestine (Orskov, 1982). In early work by Orskov et al. (1970) fecal nitrogen output was increased due to ileal starch infusion in sheep. Goetsch and Owens (1984) infused starch into the ileum of steers and noted a slight depression in apparent total tract nitrogen digestion and an increase in microbial nitrogen exiting the rectum. Mason et al. (1977) infused cellulose and starch into the caecum of sheep and reported increases in fecal nitrogen excretion, with cellulose having less of an effect than starch. Urinary nitrogen was monitored in the same study, as fecal nitrogen content increased due to starch or cellulose degradation urinary nitrogen decreased. This suggests that the primary source of nitrogen in the large intestine is diffused blood urea. Gelatine infusion by Mason et al. (1977) demonstrated that excess nitrogen in the large intestine diffuses into the blood, raising blood urea levels and is subsequently excreted in the urine. In comparison to the rumen and small intestine, very little work has been conducted to determine the efficiency of fermentation in the large intestine and the effects of fermentation in the large intestine on animal production.

Condensed tannins have been associated with reduced performance in the feeding of several classes of livestock. The small intestine can be particularly susceptible to the detrimental effects of tannins, because tannins bind non-specifically to digestive enzymes. Tannins inhibit digestion in the small intestine by complexing with enzymes and substrates. Trypsin, α-amylase, and α-glucosidase have been reported to be non-competitively inhibited by condensed tannins (McLeod, 1974). Barry and Duncan (1984) have suggested that when plant proteins are saturated with tannins, free tannins will be present to bind in the small intestine. Davis and Hoseney (1979a) have suggested that starch selectively adsorbs condensed tannins, thereby limiting intestinal starch digestion. In vitro studies conducted by Armstrong et al. (1974) demonstrated that protein digestibility of high tannin bird resistant sorghum grain is depressed when compared to low tannin non-bird resistant types. Their study further shows that extraction of condensed tannins resultes in an improvement in protein digestibility. Barry and Manley (1984) demonstrated that the presence of condensed tannins in lotus (tannin containing legume) reduced ruminal non-ammonia nitrogen disappearance while increasing the amount of non-ammonia nitrogen absorbed post ruminally. Increased post ruminal absorption of nitrogen would not appear to occur with other condensed tannin containing plants. Hibberd in 1982 observed decreased ruminal and post ruminal nitrogen digestion in association with bird resistant sorghum grain diets fed to steers. Fecal nitrogen output increased when rats were fed tannin containing grape seeds by Glick and Joslyn (1969).

Several researchers have suggested that the inhibitory effects of sorghum tannins on protein digestion may be overcome by the addition of methionine (Armstrong et al., 1973), protein (Shaffert et al., 1974) polyvinyl pyrrolidone, urea, polyethyleneglycol, and formaldehyde (McLeod, 1974). Methionine and protein may overcome detrimental effects of sorghum tannins by complexing with free tannins thereby preventing enzyme inhibition. Poly vinylpyrrolidone, urea, polyethyleneglycol and formaldehyde are bound preferentially by condensed tannins; therefore, proteins are free to be degraded (McLeod, 1974).

The metabolic fate of condensed tannins in cattle has not been determined; however, Potter and Fuller (1968) identified metabolic products from the break down of dietary tannic acid in the urine of chickens. Sell and Rogler (1983) monitored the activity of liver microsomal UDP-glucuronyl transferase (an enzyme known to detoxify phenolic compounds) in chicks and rats fed high and low tannin sorghum. UDP-glucuronyl transferase activity was increased 63% due to feeding high tannin sorghum to chicks. Increased activity of the liver may be associated with reduced protein absorption (Sell and Rogler, 1983). However, in the study conducted by Sell and Rogler (1983) this possible explanation of increased activity was examined and found not to be responsible for the observed increase. No increase in UDP-glucuronyl transferase was observed in the rat associated with feeding high tannin sorghum. It appears that species differences do exist. Further research is needed to determine the metabolic fate of condensed tannins in cattle. Tannins may cause reduced performance in cattle due to effects on liver metabolism to a greater extent than those factors investigated to date. Increased demands on the liver in combination with decreased protein available for absorption from the small intestine could result in reduced animal performance.

Nitrogen Flow to the Duodenum and Microbial Efficiency

Microbial protein constitutes an extremely important source of nitrogen reaching the small intestine. From 40 to 80% of the available protein reaching the duodenum comes from microbial protein (Owens and Bergen, 1983). Nitrogen flow may be effected by such factors as level of feed intake, roughage to concentrate ratio, and physical form of the ration. Factors associated with alterations in nitrogen flow and/or microbial efficiency may also influence ruminal dilution rate.

Increasing the level of feed intake from 1.2 to 2.1% of body weight resulted in a 59% increase in total nitrogen flow to the small intestine in a study by Zinn and Owens (1983a). Similarly, feed protein escaping ruminal degradation increased 38% and microbial protein reaching the duodenum increased by 48%. Effects of increasing feed intake may be the direct result of increasing the amount of fermentable substrate available to the rumen microbes and increasing ruminal dilution rate (Zinn and Owens, 1980; Bergen et al., 1982).

Level of roughage may also greatly influence nitrogen flow and microbial efficiency. Cole et al. (1976b) noted a substantial increase in nitrogen reaching the small intestine (70.3 versus 126.3 g/day) as roughage level increased (0% to 21%). At higher roughage levels (14 to 21%), nitrogen reaching the small intestine exceeded nitrogen intake by 18.3% and 7.6%, respectively, indicating greater nitrogen recycling caused by an increase in salivary flow (Cole et al., 1976b). Microbial nitrogen reaching the duodenum tended to increase with roughage; however, as a percent of total nitrogen reaching the small intestine little differences existed between treatments. Faster ruminal liquid dilution rates, which may result from increased salivation with roughage feeding, have been shown by Issacson et al. (1975) to support greater microbial efficiencies in vitro. Weakley (1983) demonstrated that microbial efficiency increases with roughage level in vivo.

The physical form of a ration alters nitrogen flow and microbial efficiency (Bergen et al., 1982). Cole et al. (1976b) reported greater total nitrogen flow through the abomasum for dry rolled corn versus steam flaked corn. All protein fractions showed an increase, (non-ammonia nitrogen 18%, microbial nitrogen 14%, and feed bypass nitrogen 21%). A 34% increase in efficiency of microbial protein synthesis was observed for dry rolled corn over steam flaked corn diets. Cole et al. (1976b) suggested rations that should have more rapid fermentation rates (steam flaked corn and lower roughage rations) may have lower microbial protein synthesis per unit of dry matter fermented. Zinn et al. (1981) suggested a large portion of energy from highly fermentable feeds normally used for protein synthesis may be diverted to produce microbial polysaccharides for storage thereby reducing the efficiency of microbial protein synthesis. Increases in total nitrogen reaching the duodenum have been associated with reconstituted sorghum grain (Hibberd, 1982) and ground high moisture harvested corn (Prigge et al., 1978), when compared to their respective dry rolled counterparts. Hibberd (1982) reported increased chyme flow associated with reconstitution suggesting that ruminal liquid dilution rate may have been increased. Prigge et al. (1978) reported that steam flaked and ground high moisture corn had a greater microbial efficiency than dry rolled corn. Acid treatment of high moisture corn further enhanced microbial efficiency above that observed for ground high moisture corn (Prigge et al., 1978).

Increasing ruminal dilution rate probably reduces the maintenance requirements of the microbes; thereby, increasing microbial efficiency (Bergen and Yokoyama, 1977). Chemical and physical factors that altered rumen turnover rate should therefore be useful in increasing the efficiency of microbial protein synthesis. Cole et al. (1976b) noted a 36% increase in microbial efficiency as dilution rate increased from 2.8 to 5.0% per hour. Maintenance requirements may also be effected by the presence of growth inhibiting substances (Bergen and Yokoyama, 1977) such as condensed tannins (Benson et al., 1984).

Solid retention time has also been implicated as a potentially important factor effecting microbial efficiency in vitro (Crawford, et al., 1980). No significant effect of liquid dilution rate was observed by Crawford et al. (1980); however, decreasing solid retention time increased microbial efficiency. In vivo one would expect passage of bacteria from the rumen to be more related to the rate of solid flow than liquid flow; however, as liquid dilution rate increases solids are likely to be carried out of the rumen more rapidly. Greater study is needed to determine the importance of solid passage rate on microbial efficiency and nitrogen flow to the duodenum.

The importance of ruminal bypass of cereal grain protein needs careful consideration. Cereal grains contain poor quality proteins. Their bypass to the small intestine, rather than degradation in the rumen may actually decrease the availability of essential amino acids to the host animal. Sorghum grain may be particularly susceptible to problems that may arise from ruminal bypass of grain protein. Protein encapsulation of sorghum starch may result in a reduction of starch digestion in the small intestine when greater amounts of sorghum protein escape the rumen.

Use of Cannulated Animals

Cannulation has become a popular method of determining site and extent of nutrient digestion in recent years. Cannulation has several advantages over traditional slaughter techniques used to determine partial digestion coefficients. Animals can be used for a number of experiments, more importantly the trauma associated with slaughter may alter apparent digestion. The development of rare earth markers used to monitor liquid and particulate flow rates have further enhanced the use of cannulated animals. Two basic types of cannulae are available, re-entrant and T-type. T-type cannulae appear to cause the least disturbance of intestinal motility (Wenham and Wyburn, 1980); however, problems do exist. Marker use is required and the randomness of a sample is difficult to determine and control. The integrity of the intestine near the cannulae tends to deteriorate over time resulting in mixing pools and digesta stratification. Recent developments in surgical techniques, cannulae placement and cannulae construction may help to control some of these problems (McGilliard, 1982).

Further consideration must be given to the effects of cannulation on nutrient dietary, liquid/solid passage rates, and voluntary feed intake. Nutrient digestion although altered slightly is not significantly different from non-fistulated steers (Hayes et al., 1964). Liquid and solid phase markers have shown little change in flow rates due to surgery (MacRae and Wilson, 1977). Voluntary feed intake (VFI) may show a variable response. VFI may be greatly reduced in animals equipped with re-entrant cannulae, if the cannulae becomes blocked or restrictive of digesta flow (McGilliard, 1982); however, problems with T-type cannulae appear to be less prevalent.

CHAPTER III

THE EFFECT OF SORGHUM GRAIN VARIETY ON SITE AND EXTENT OF DIGESTION IN BEEF HEIFERS

ABSTRACT

Darset (Dar), 1133, Dwarf Redlan (Dwf), pureline sorghum grain varieties and commercially purchased millrun (Mr) sorghum were dry rolled and fed in an 88% grain ration to determine the effect of variety on site and extent of digestion. Darset is a high tannin, bird resistant type with normal endosperm. 1133 is a high tannin bird resistant type with waxy endosperm. Dwarf Redlan has a waxy endosperm and is a non-bird resistant type. Diets were fed at 2% of body weight (DM basis) in a 4x4 Latin square using four Hereford-Angus heifers (230 kg) with ruminal, duodenal, and ileal T-type cannulae. Total tract starch digestibility was similar (P>.05) for all varieties, averaging 90.8%. Ruminal starch digestion tended to be higher (P<.15) for bird resistant (1133 and Dar) than non-bird resistant varieties (Dwf and Mr). Starch digestibility through the ileum was greater (P<.10) for waxy (1133 and Dwf) when compared to normal (Dar and Mr) varieties. The large intestine was a more important (P<.15) site of starch digestion (% of intake) for normal varieties with, 398g of Mr and 251g of Dar starch disappearing in the large intestine. Total tract nitrogen (N) digestion was higher (P<.01) for non-bird resistant types, Dwf (69.0%) and Mr (63.8%) than bird resistant types, 1133 (54.0%) and Dar (47.8%).

Additionally, ruminal feed N disappearance was higher ($P<.05$) for non-bird resistant types (Dwf, 51.7%; Mr, 46.2%) than for bird resistant types (Dar, 35.4%; 1133, 27.8%). Nitrogen disappearance was nearly complete by the ileum for all varieties (98.4%). Sorghum with a waxy endosperm tended to have improved N digestion post ruminally. Sorghum grain variety appears to alter site and extent of nutrient digestion which may alter animal performance.

Introduction

Sorghum grain is becoming an increasingly important cereal grain in the Great Plains. Diminishing water supplies and increasing cost of irrigation have caused great interest in sorghum grain which requires less water than corn and can be successfully grown under dryland conditions. Sorghum grain is often discriminated against because of variable quality (Miller et al., 1962) and a lower feeding value than corn (NRC, 1984). Inconsistent cattle growth rates and efficiences have been associated with different varieties (McCullough et al., 1972; Maxson et al., 1973). Some of the variation in performance may be due to differences in digestibility (Samford et al., 1970; McCollough and Brent, 1972).

Limited evidence suggests endosperm type can effect digestibility. Miller et al., (1972) observed that grain with a floury endosperm had higher nylon bag digestibility. Grains with floury endosperm, however, tend to have a low density and test weight, limiting commercial usefulness (Sullins and Rooney, 1974). Grains with a waxy endosperm, have been shown to have increased digestibility (Nishimuta et al., 1969;

Hibberd et al., 1982a,b) and may have less peripheral endosperm and amorphous protein matrix (Sullins and Rooney, 1974).

Tannins decrease bird deprivation and inhibit preharvest mold. Condensed tannins, however, reduce starch digestion in vitro (Saba et al., 1973; Hibberd et al., 1982 a,b), and feed efficiency (McCollough and Brent, 1972) and nitrogen digestibility in vivo (Armstrong et al., 1973; Shaffert et al., 1974; Hibberd et al., 1985).

Endosperm characteristics and bird resistance may alter ruminal fermentation and intestinal digestion and absorption, thereby altering efficiency (Black, 1971). The extent to which different sorghum grain varieties alter site and extent of nutrient digestion has received only limited study and is largely unknown. The relationship between grain characteristics, such as tannin content or starch waxiness and digestive function are unclear. The objectives of the study; therefore, were to evaluate the effects of four widely divergent sorghum grain varieties on; 1. chemical composition and in vitro digestibility of the grain, 2. extent of starch digestion in the rumen, small and large intestines and, 3. extent of sorghum protein escape to the small intestine and subsequent digestion in beef cattle.

Materials and Methods

Dwarf Redlan (Dwf), 1133 and Darset (Dar), pureline sorghum grain varieties were grown under dryland conditions at the Perkins Agronomy Experiment Station, Perkins, OK. A fourth variety, millrun (Mr), was purchased commercially through the Oklahoma State University feedmill. Origin and genetic background of Mr were unknown, but appeared to be representative of that normally purchased on a commercial basis and was a normal endosperm, non-bird resistant type. Observable physical characteristics of the varieties are listed in Table 1. All varieties were dry rolled and incorporated into an 88% grain diet (Table 2). Urea was used as the sole source of supplemental N and cottonseed hulls as the roughage source (containing approximately .3% total dietary N) so that feed N reaching the duodenum would be primarily of grain origin.

Laboratory Phase

Grain and feed samples were ground through a Udy mill (1mm screen) before compositional analyses. Dry matter (DM, A.O.A.C., 1975), starch (MacRae and Armstrong, 1968), crude protein (A.O.A.C. 1975), organic matter (OM, A.O.A.C. 1975) and acid detergent fiber (ADF, Goering and Van Soest, 1970) contents were determined. Condensed tannin content was determined using a vanillin-HCl procedure (Burns, 1971) as modified by Price et al. (1978) and is reported as catechin equivalents per gram of DM. Grain samples were further analyzed for pepsin insoluble nitrogen (PIN, Goering and Van Soest, 1970) and sodium chloride (NaCl) soluble protein (Waldo and Goering, 1979).

In vitro dry matter disappearance (IVDMD) was estimated using grain and feed samples ground through a 20 mesh (1mm) screen in a laboratory Wiley mill. IVDMD was calculated by difference in weight after an 18 hour incubation at 39 C with buffered rumen fluid (15 ml rumen fluid: 15 ml McDougall's buffer; McDougall, 1948). Ruminal fluid was obtained from two different heifers, one consuming a bird resistant sorghum grain (Dar), the other a non-bird resistant sorghum grain (Mr) diet. Samples were incubated in each fluid to determine if microbes adapt to high tannin diets.

TABLE I

DESCRIPTIVE CHARACTERISTICS OF SORGHUM GRAIN VARIETIES

Sorghum Variety	Abbreviation	Pericarp Color	Endosperm Color	Endosperm Starch Type	Testa* Layer
Dwarf Redlan	Dwf	red	white	waxy	absent
1133	1133	brown	yellow	waxy	present
Darset	Dar	brown	white	normal	present
Millrun	Mr	mixed	non-descript	normal	absent

* Presence of testa layer indicative of high tannin content and bird resistance.

TABLE II

INGREDIENT COMPOSITION OF EXPERIMENTAL DIETS

Ingredient	% of dry matter
Sorghum grain	88.78
Cottonseed hulls	7.22
Supplement	
Urea	1.20
Dicalcium phosphate	0.44
Calcium carbonate	0.93
Potassium chloride	0.57
Sodium sulfate	0.36
Chromic oxide	0.20
Vitamin A	2200 IU/kg

In vitro gas production (IVGP) of the grains was determined by measuring the CO_2 produced by .25g of commercial baker's yeast incubated at 39 C with 1 g of grain and 10 ml of a 0.1% (W/V) amyloglucosidase solution (Hibberd et al., 1982a). Gas production measurements were made hourly from 0 to 6 h and at 12 h after initial incubation began. IVGP data were analyzed to determine differences in total gas produced at 6 and 12 h.

Animal Phase

Four Hereford-Angus heifers (230 kg) were fitted with ruminal, duodenal (4 cm distal to the pylorus) and ileal (20 cm cranial to the ileo-cecal junction) T-type cannulae. Heifers were fed 4 rations, differing in sorghum grain variety (Table 2) at 2% (DM basis) of body weight in a 4x4 Latin square. Experimental periods were 10 days in length, with days 1 through 7 being used for adaptation and 8 through 10 for sampling. Heifers were fed equal portions at 0800 and 2000 h and sampled at 1000, 1400 and 1800 h. Feed samples were collected on days 7 through 9 and composited across day. Ruminal fluid was collected for ammonia (NH_3) and pH determination on the last day of each period. Ruminal samples were acidified with 3.3 ml of 36 N H_2SO_4 per 1000 ml of fluid immediately after determination of pH. Ruminal (1000 ml), digesta (500 ml duodenal and 250 ml ileal fluid per time) and fecal grab samples were composited across time and day within animal for each period after pH determination and stored at 5 C until the end of each period. Subsamples of ruminal, duodenal and ileal fluids and fecal matter were obtained and stored at -20 C.

Ruminal fluid (2000 ml/d) used to estimate bacterial nucleic acid N, total N and OM was collected on the last day of sample collection at 1400 h during period 2. Bacteria were isolated from rumen fluid 1 d after collection by differential centrifugation (Weakley, 1983), frozen (-20 C), lyophilized and ground with a mortar and pestle.

Digesta and fecal samples were dried using a lyophilizer prior to grinding through a 1mm screen in a Udy mill for chemical analysis. Feed, ruminal, bacterial, duodenal, ileal and fecal samples were analyzed for all components used in the laboratory phase in addition to: ammonia (NH_3) N by magnesium oxide distillation (A.O.A.C. 1975), total purines (Zinn and Owens, 1982) and chromic oxide (Fenton and Fenton, 1979).

Partial digestion coefficients and amounts of different components presented to and disappearing from segments of the digestive tract were determined by chromic oxide ratios. Microbial-N reaching the duodenum was calculated as nucleic acid-N divided by the ratio of total microbial nucleic acid N to total microbial N for each heifer in period 2. In period 1, 3 and 4 microbial N was calculated using an average microbial nucleic acid N to microbial N ratio of period 2 (.17). Feed N (plus endogenous N) reaching the duodenum was calculated as total duodenal N minus NH_3-N and microbial N. Organic matter reaching the duodenum was corrected for microbial OM based on determined values of 41.94% crude protein and 26.31% ash content for the microbes. Corrected ruminal OM disappearance was used to calculate true microbial efficiency (g microbial N/kg OM truly fermented in the rumen).

Statistical Analysis

Data from IVDMD can be described by the following model: $Y_{ijkl} = \mu + F_i + P(F)_j + V_k + F_i * V_k + E_{ijkl}$, where Y_{ijkl} is the observed value, F is the rumen fluid source, P(F) is the period within fluid source, V is the sorghum grain variety and F * V is the interaction between rumen fluid and sorghum grain variety. All effects except fluid were tested for significance using the residual mean square. Fluid mean square was tested using the period within fluid mean square. Random errors, E_{ijkl}, were specific to each observation. IVGP can be described by the following model: $Y_{ijk} = \mu + V_i + R_j + E_{ijk}$, where Y_{ijk} is the observed value of interest, V is the variety of interest and R is the run. The components μ, V_i, and R_j were treated as fixed effects of all records of variety i and run j. Random errors, E_{ijk}, were specific to each observation.

The data from the animal phase (4x4 Latin square) of the experiment can be described by the followed model: $Y_{ijk} = \mu + A_i + P_j + V_k + E_{ijk}$, where Y_{ijk} is the observed value of interest, A is animal, P is period and V is variety of sorghum grain. The components μ, A_i, P_j and V_k were treated as fixed effects of all records of animal i, period j and variety k. Random errors, E_{ijk}, were specific to each observation.

Differences between treatment means were obtained based upon least squares analysis. Comparisons between treatment means were based on the orthogonal contrasts listed in Table 3.

TABLE III

ORTHOGONAL CONTRASTS BETWEEN TREATMENTS

	Sorghum variety			
Contrast	1133	Dar	Dwf	Mr
Bird resistants vs non-bird resistants	-1	-1	+1	+1
Waxy vs normal	+1	-1	+1	-1
Interaction of waxy and bird resistants	-1	+1	+1	-1
1133 vs Dwarf Redlan	+1	0	-1	0
Darset vs millrun	0	+1	0	-1
Dwarf Redlan vs millrun	0	0	+1	-1
1133 vs Darset	+1	-1	0	0

Results and Discussion

Laboratory Phase

Crude protein content (Table 4) was greater ($P<.05$) for Dwf (12.4%) than Mr (10.3%). Dar (13.2%) contained a greater ($P<.01$) amount of crude protein than 1133 (12.0%). Dar also contained a greater ($P<.01$) amount of crude protein than Mr. Differences in crude protein content between complete mixed feeds reflected differences in grain variety.

Starch content was greatest for the Mr grain (78.8%) and lowest for Dar (72.1), with Dwf (77.1%) and 1133 (76.4%) being intermediate. Complete mixed feeds did not reflect the starch content of the grains. Dwf (68.2%) contained a greater amount of starch than did Mr (62.3%), while 1133 (63.3%) and Dar (64.0%) were similar to each other.

Condensed tannin content of the bird resistant varieties was higher ($P<.01$) than the non-bird resistant varieties. High condensed tannin content is typical of bird resistant sorghum grain varieties (Price et al., 1979b).

Sodium chloride soluble protein content appeared to be greater for the non-bird resistant varieties. The waxy, bird resistant variety, 1133 (4.2%); however, had a greater soluble protein content than the normal bird resistant Dar (2.1%). Increased soluble protein content has been previously reported for waxy sorghum grains (Walker and Lichtenwalner, 1977). Within bird resistant varieties, Dar (22.0%) contained more ($P<.01$) PIN than 1133 (18.3%). Within waxy and normal varieties 1133 contained more ($P<.01$) PIN than Dwf (13.3) and Dar more

TABLE IV

CHEMICAL COMPOSITION OF SORGHUM GRAIN VARIETIES AND COMPLETE MIXED FEEDS (DRY MATTER BASIS)

Item	1133	Dar	Dwf	Mr	SE
Grain					
Crude protein(%)[abcd]	12.0	13.2	12.4	10.3	.09
Starch(%)	76.4	72.1	77.1	78.8	2.83
Tannin(cat. eq./g)[e]	1.24	1.44	0.00	0.00	.060
NaCl soluble protein(%)	4.2	2.1	7.5	7.4	1.99
Pepsin insoluble nitrogen(%)[bdfg]	18.3	22.0	13.3	13.8	.35
Feed					
Crude protein(%)[abch]	13.5	14.4	14.3	12.1	.22
Starch(%)[i]	63.3	64.0	68.2	62.3	1.60
Ash(%)	4.11	3.96	4.34	3.84	.175
ADF(%)[e]	11.23	10.33	8.21	8.53	.459
Tannin(cat. eq./g)[bdfg]	1.24	1.54	0.02	0.02	.050

[a]Interaction (P<.01).
[b]Darset vs millrun (P<.01).
[c]Dwarf Redlan vs millrun (P<.01).
[d]1133 vs Darset (P<.01).
[e]Bird resistant vs non-bird resistant varieties (P<.01).
[f]Interaction (P<.05).
[g]1133vs Dwarf Redlan (P<.01).
[h]1133 vs Dwarf Redlan (P<05).
[i]Interaction (P<.10).

(P<.01) than Mr (13.8%). Hibberd (1982) reported bird resistant to contain more PIN than non-bird resistant sorghum grain.

Acid detergent fiber (ADF) content of the bird resistant complete mixed feeds was higher (P<.01) than the non-bird resistant feeds. Increased ADF content is probably caused by tannin. Van Soest (1982) suggests that when tannins are present analytically they will appear as ADF.

An IVDMD study (Table 5) was conducted to determine potential adaptation to the high tannin levels. Incubation of sorghum varieties in ruminal fluid collected from a heifer fed Dar tended to result in a lower (.10<P<.25) IVDMD than when fed Mr (Figure I). IVDMD averaged across ruminal fluid source and within bird resistance was lower for (P<.01) normal Dar (30.9%) than waxy 1133 (35.4%). IVDMD for waxy Dwf (44.3%) was greater (P<.01) than for waxy 1133. within normal varieties, Mr (44.0%) had a higher (P<.01) IVDMD than Dar (30.9%). Other IVDMD data with these same sorghum varieties is in agreement with the results reported herein (Hibberd et al., 1982 a,b). Poor correlation of IVDMD with ruminal starch (r = -.03), OM (r =.16) and feed N (r = -.09) digestibilities in this study make these data difficult to interpret, but in this case IVDMD appeared to do a poor job of estimating ruminal responses. Previous work by Hibberd et al. (1985), however, illustrated that ruminal starch digestion was not depressed by bird resistant characteristics in sorghum grain. Benson et al. (1984) suggested that some rumen bacteria may be sensitive to phenolic compounds presumably similar to metabolites of condensed tannins.

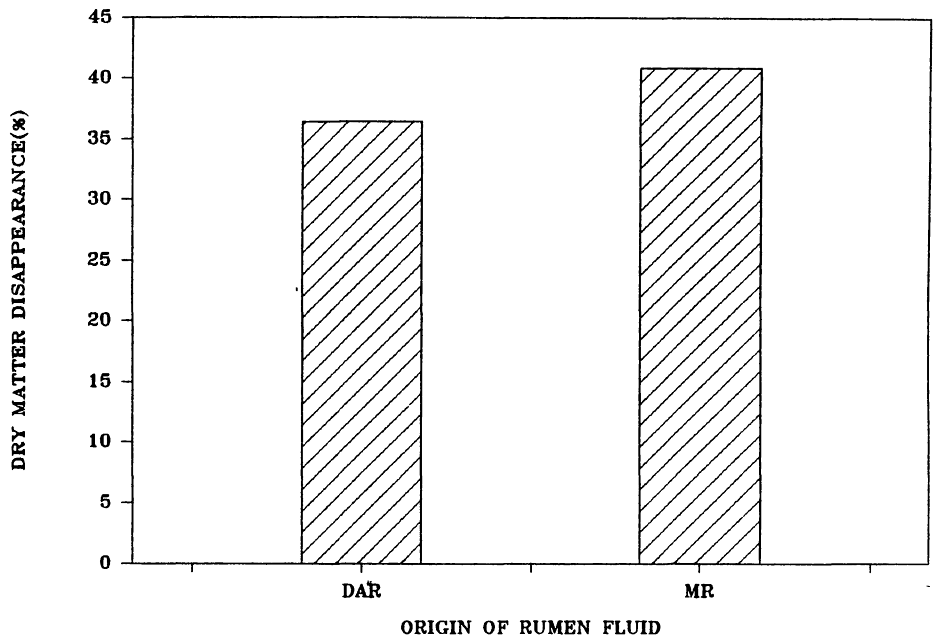

Figure 1. Comparison of Rumen Fluid Sources for IVDMD

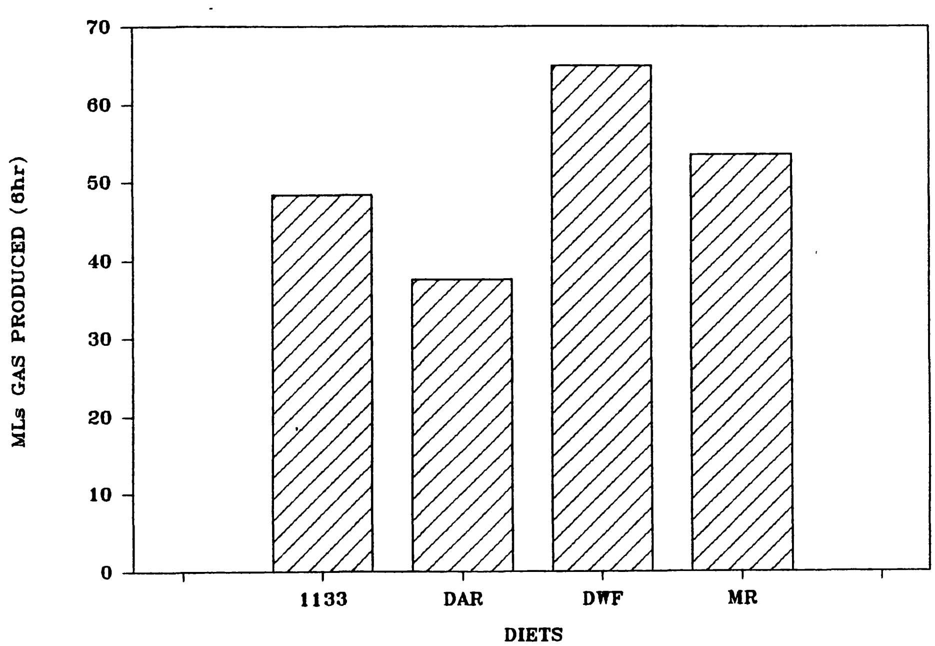

Figure 2. IVGP of Sorghum Grain Varieties (6 h)

TABLE V

IN VITRO DRY MATTER DISAPPEARANCE AND IN VITRO GAS PRODUCTION OF SORGHUM GRAIN VARIETIES

Item	1133	Dar	Dwf	Mr	SE
IVDMD(% averaged across variety & w/n fluid)[a]		36.4		40.9	.61
IVDMD(% averaged across fluid) [bcde]	35.4	30.9	44.3	44.0	.86
IVGP(ml gas/g DM)					
6 hours[fg]	48.4	37.5	64.9	53.5	2.50
12 hours[fg]	65.2	52.2	85.1	77.2	3.08

[a]Dar fluid vs Mr fluid (.10<P<.25).
[b]Interaction (P<.05).
[c]1133 vs Dar (P<.01).
[d]1133 vs Dwf (P<.01).
[e]Dar vs Mr (P<.01).
[f]Bird resistant vs non bird resistant varieties (P<.01).
[g]Waxy vs normal varieties (P<.01).

In vitro gas production (Figure 2) at 6 and 12 h was greater ($P<.01$) for non-bird resistant varieties. Within bird resistant varieties, waxy 1133 had greater gas production at both 6 and 12 h than Dar. Waxy varieties (1133 and Dwf) averaged more ($P<.01$) CO_2 production at 6 and 12h than normal varieties (Dar and Mr).

Animal Phase

Total tract OM and starch digestion were similar for all varieties (Table VI). Although not significant bird resistant varieties tended to have lower OM and starch digestibilities than non-bird resistant varieties. Moreover, ADF digestion was much lower ($P<.01$) for bird resistant and normal varieties ($P<.05$) on the average. Lower ADF digestion may result from inhibition of hemicellulose digestion by tannins in the bird resistant sorghum grains (Barry and Manley, 1984). Furthermore, Van Soest (1982) suggested that tannins appear as ADF analytically.

Total tract N digestion was reduced for bird resistant diets, based upon total fecal N and non-NH_3 N ($P<.01$). Reduced N digestion in bird resistant sorghum grain has been reported by other researchers (Hibberd et al., 1985; McCollough and Brent, 1972). Within each tannin grouping, varieties with waxy endosperm (1133 and Dwf) appeared to have greater total tract non-NH_3 N digestibiltiy (Figure 3) than their normal counterparts (Dar and Mr). Lichtenwalner et al. (1978) reported that the waxy characteristic resulted in increased N digestibility of sorghum grains.

Ruminal Digestion. Due to higher protein content of Dwf and Dar grains, N intakes were higher for heifers fed Dwf (103.5 g/d) and

TABLE VI

EFFECT OF SORGHUM VARIETY ON TOTAL TRACT NUTRIENT DIGESTION

Item	1133	Dar	Dwf	Mr	SE
Fecal output (kg/day)	5.94	6.20	5.36	5.00	.822
Fecal pH[a,b,c]	5.95	6.13	5.93	5.59	.107
Feces (g/day)					
Organic matter	1242	1393	1061	1108	176.8
Starch	230.1	292.9	262.6	268.2	102.15
Acid detergent fiber[a,d,e,f]	391.2	387.7	194.5	254.8	31.4
Tannin (cat.eq./day)[g]	16.9	17.0	2.4	2.5	1.52
Total N[g]	45.2	54.8	32.9	32.2	3.82
Ammonia N[b,c,h]	0.77	0.92	0.80	0.64	.066
Non-ammonia N[g]	44.7	53.8	32.1	31.5	3.80
Total tract digestibility(%)					
Organic matter	71.0	67.4	75.4	74.2	4.16
Starch	91.8	89.8	91.4	90.4	3.43
Acid detergent fiber[g,i]	22.6	17.7	47.5	35.0	8.0
Tannin[g]	69.4	75.4	-107.2	-231.8	56.96
Digetibility of total feed N based on:					
Total fecal N[g]	53.2	46.9	68.2	63.0	3.93
Fecal non-ammonia N[g]	54.0	47.8	69.0	63.8	3.91

[a]Interaction (P<.10).
[b]Dwf vs Mr (P<.10).
[c]Dar vs Mr (P<.05).
[d]Dwf vs Mr (P<.05).
[e]1133 vs Dwf (P<.01).
[f]Dar vs Mr (P<.01).
[g]Bird resistant vs non-bird resistant varieties (P<.01).
[h]Interaction (P<.05).
[i]Waxy vs normal varieties (P<.05).

Dar(103.2 g/d) vs 1133 (96.7 g/d) and Mr (87.0 g/d) (Table VII). With all diets there was a net gain in nitrogen reaching the duodenum above intake. A gain in N through the rumen reflects increased N recycling to the rumen (Kennedy and Milligan, 1980). Low ruminal NH_3 concentrations across all diets may indicate marginal N to maintain maximal microbial growth and dry matter digestion (Satter and Slyter, 1974; Weakley, 1983). Alternatively, rapid uptake of NH_3 by rumen bacteria with more fermentable grains may result in low ruminal NH_3 concentrations.

Total N ($P<.05$) (Figure 4), non NH_3 non microbial N ($P<.01$) and ADF ($P<.05$) (Figure 5) reaching the duodenum (g/d) were greater for bird resistant varieties. Tannin entering the duodenum was much greater, as expected, for bird resistant grains ($P<.01$). Duodenal chyme flow (l/d) (Figure 6) tended to be greater ($P<.10$) with Dar (49.8 l/d) than 1133 (43.6 l/d). Normal Dar resulted in greater ($P<.05$) chyme flow than normal Mr (40.0 l/d). Hibberd et al. (1985) reported increased chyme flow with a bird resistant sorghum. Increased chyme flow may reflect increased ruminal liquid dilution rate and tended to be associated with decreased digestibility in the rumen ($r = -.96$; $P<.20$).

Corrected ruminal OM digestion was similar for all diets ranging from 50.3% for 1133 to 56.7% for Dwf. Although not significant, non-bird resistant diets tended to yield higher digestibilities. Ruminal starch digestibility did not differ significantly between diets, but bird resistant varieties tended to be higher ($P<.15$). Hibberd et al. (1985) found a bird resistant sorghum grain having a higher ($P<.05$) ruminal starch digestion coefficient than a non-bird resistant grain. Explanations for this trend are not clear, however, it appears that some concentration of tannins may enhance ruminal starch digestion. IVDMD

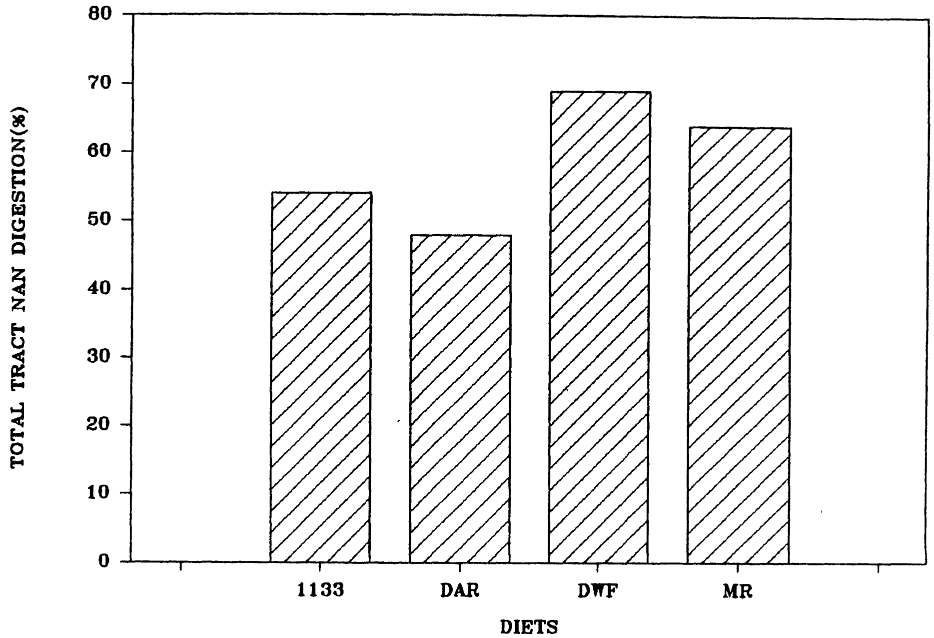

Figure 3. Total Tract Non-Ammonia N Digestion

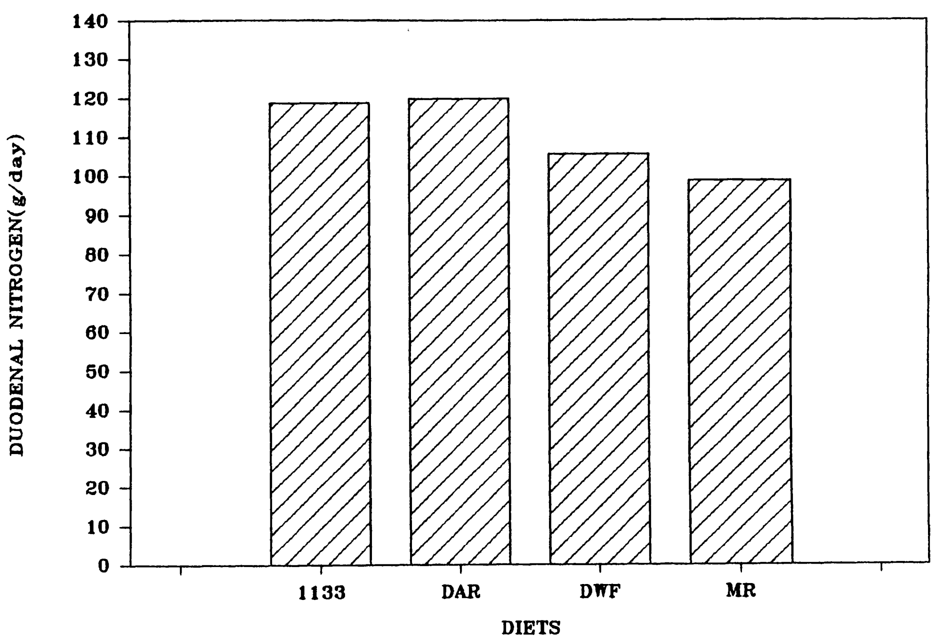

Figure 4. N Flow to the Duodenum (g/d)

TABLE VII

EFFECT OF SORGHUM VARIETY ON RUMINAL NUTRIENT DIGESTION

Item	1133	Dar	Dwf	Mr	SE
Intake (g/day)					
Organic matter	4279	4270	4330	4292	
Starch	2825	2865	3085	2796	
Acid detergent fiber	505.4	470.9	374.4	392.2	
Tannin(cat.eq./day)	55.3	69.2	1.1	0.8	
Total feed N	96.7	103.2	103.5	87.0	
Feed N(excluding urea N)	71.7	78.2	78.2	61.8	
Rumen					
pH	6.28	6.40	6.14	6.22	.089
Ammonia N (mg/dl)	3.42	4.47	3.74	4.55	.836
Entering the duodenum (g/day)					
Chyme (l/day)[abc]	43.6	49.8	42.9	40.0	1.8
Chyme pH	2.05	2.02	1.97	2.08	.08
Total organic matter	2596	2524	2417	2420	166.2
Non microbial OM	2127	2024	1882	1911	170.3
Starch	640.8	711.6	804.8	875.6	88.74
Acid detergent fiber[d]	516.8	417.1	293.6	354.4	45.89
Tannin(cat.eq./day)[e]	15.3	16.6	1.6	3.4	2.02
Total N[d]	118.6	119.7	105.4	98.7	4.86
Ammonia N[af]	5.28	6.60	5.83	4.65	.575
Microbial N	43.5	46.4	49.7	47.3	4.86
Non-NH_3 non-microbial[e]	69.8	66.7	49.9	46.8	5.29
RNA N	7.24	7.75	8.62	8.48	0.687
Ruminal digestibility (%)					
Organic matter (corrected)	50.5	52.8	57.0	55.8	3.72
Starch	77.3	75.2	74.1	68.7	2.73
Acid detergent fiber	-2.3	11.4	21.7	9.6	11.04
Tannin[d]	72.2	76.1	-38.5	-349.4	95.02
Total feed N[d]	27.8	35.4	51.7	46.2	5.28
Feed N(excluding urea N)[d]	2.7	14.7	36.1	24.4	7.10
Ruminal escape feed N(%)[d]	97.3	85.3	63.9	75.6	7.10
Apparent microbial efficiency (g MP/kg OMF)	26.7	29.6	28.4	26.1	4.21
True microbial efficiency (g MP/kg OM truly fermented)	20.4	21.5	21.0	20.2	2.28

[a]Interaction (P<10).
[b]1133 vs Dar (P<.10).
[c]Dar vs Mr (P<.05).
[d]Bird resistant vs non-bird resistant varieties (P<.05).
[e]Bird resistant vs non-bird resistant varieties (P<.01).
[f]Dar vs Mr (P<.10).

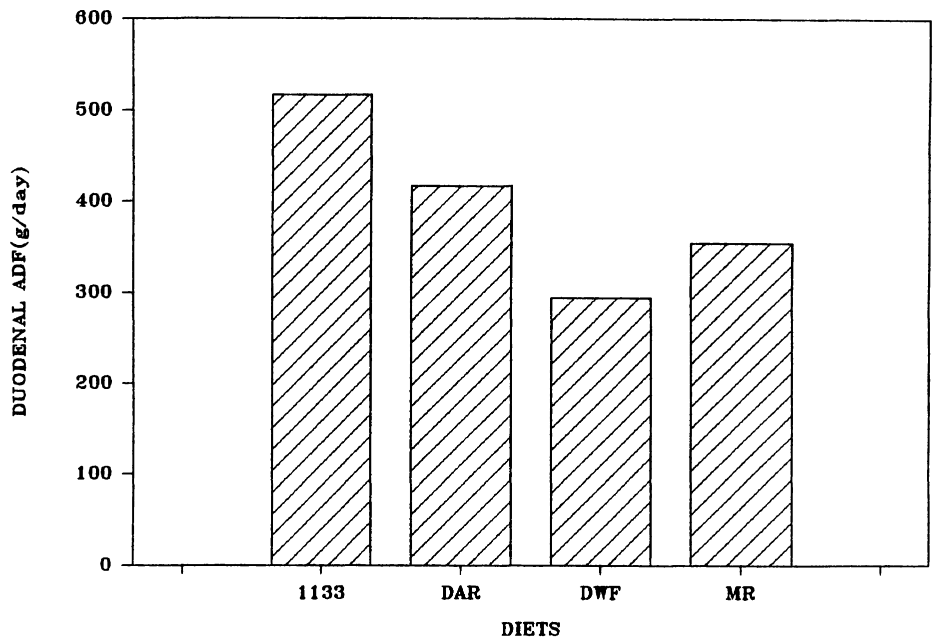

Figure 5. ADF Flow to the Duodenum (g/d)

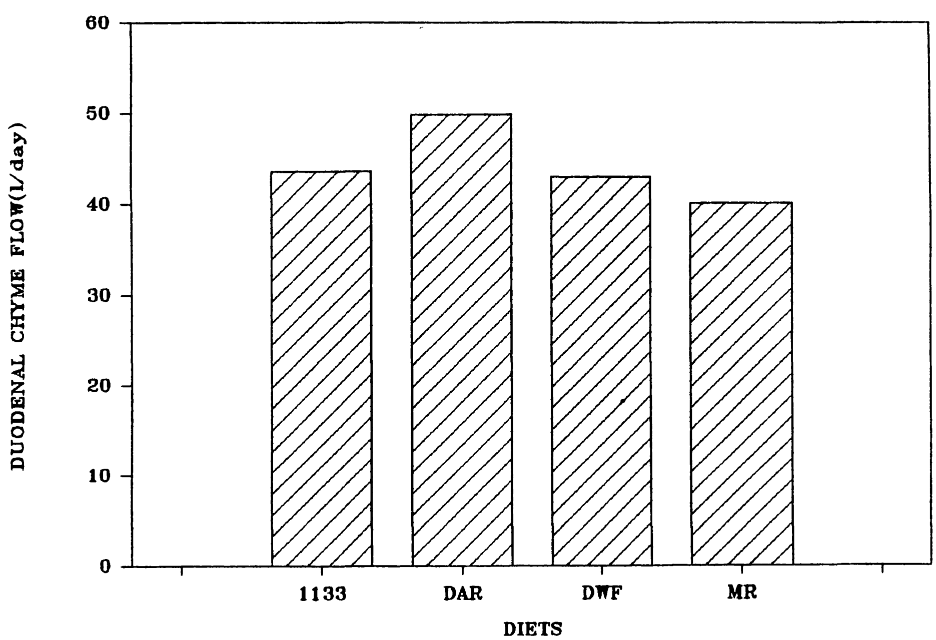

Figure 6. Chyme Flow to the Duodenum (l/d)

and IVGP values (Table V), however, suggest that non-bird resistant varieties are more digestible.

Tannin disappearance in the rumen was greater for bird resistant varieties ($P<.05$). Negative disappearances are likely an artifact of low tannin intake, potential experimental error in the vanillin-HCl procedure and a highly leveraged calculation. Tannin disappearance in the rumen and other anaerobic fermentation systems has been reported by Hibberd et al. (1985) and Reichert et al. (1980). While unknown, tannin disappearance in the rumen may occur by bacterial destruction of condensed tannin or formation of a tannin nutrient complex undetectable by the vanillin-HCl procedure. The metabolic fate of condensed tannin has not been determined in cattle; however, Potter and Fuller (1968) identified metabolic products of dietary tannic acid in the urine of chickens. Moreover, Sell and Rogler (1983) suggested depressed performance in chickens may be due to adverse effects of condensed tannins on liver metabolism. Further study is needed to determine the metabolic fate of condensed tannins in cattle and effects on liver metabolism.

Ruminal digestibility of total feed N and N excluding urea N were depressed for bird resistant varieties ($P<.05$), resulting in dramatically higher ($P<.05$) ruminal escape of feed N (Figure 7). Effects of condensed tannins and reduced protein solubility are assumed to be the mechanisms responsible for increased escape of feed N. Reports exist for decreased non-NH_3 N digestion occurring in the rumen caused by condensed tannin found in some forage species (Barry and Duncan, 1984; Barry and Manley, 1984). Soybean meal has been treated with tannin to increase ruminal N escape (Driedger and Harfield, 1972).

Hibberd et al. (1985), on the other hand, found the bird resistant characteristic had no effect on ruminal escape of feed N; however, bacteria were not obtained to assess bacterial N and OM content. Condensed tannins are known to bind preferentially to several organic compounds including urea (McLoad, 1974). The possibility exists that tannins in bird resistant sorghum diets could bind to urea, dietary or endogenous and thus, protect the urea from degradation. Undegraded urea would then appear at the duodenum as residual feed N. Aside from Hibberd et al. (1985), other reports looking at the effect of sorghum grain variety and specifically bird resistance on site and extent of N and other nutrient digestion do not exist. Tannins may have inhibited bacterial growth (Bensen et al., 1984), bacterial protease and deaminase activity (Tagari et al., 1965; Singh and Arora, 1980); thereby, increasing ruminal escape of sorghum grain protein.

In this study, bird resistant varieties tended to have lower amounts of microbial N entering the duodenum and less OM truly fermented in the rumen. However, proportionate decreases in microbial N yield and OM fermentation resulted in no effect of diet on microbial efficiency ($P>.05$).

Ileal Digestion. Greater amounts of ADF were found to be leaving the ileum (Table VIII) with bird resistant sorghum diets ($P<.01$). As expected bird resistant sorghum varieties resulted in greater amounts of tannin leaving the ileum, with Dar being greater ($P<.10$) than 1133.

As for ruminal values, total N and non-NH_3 N exiting the ileum were greater for bird resistant varieties (Figure 8), with Dar being greater ($P<.10$) than 1133 and Mr. Hibberd et al. (1985) also, reported total N and non-NH_3 N exiting the ileum to be increased with a bird

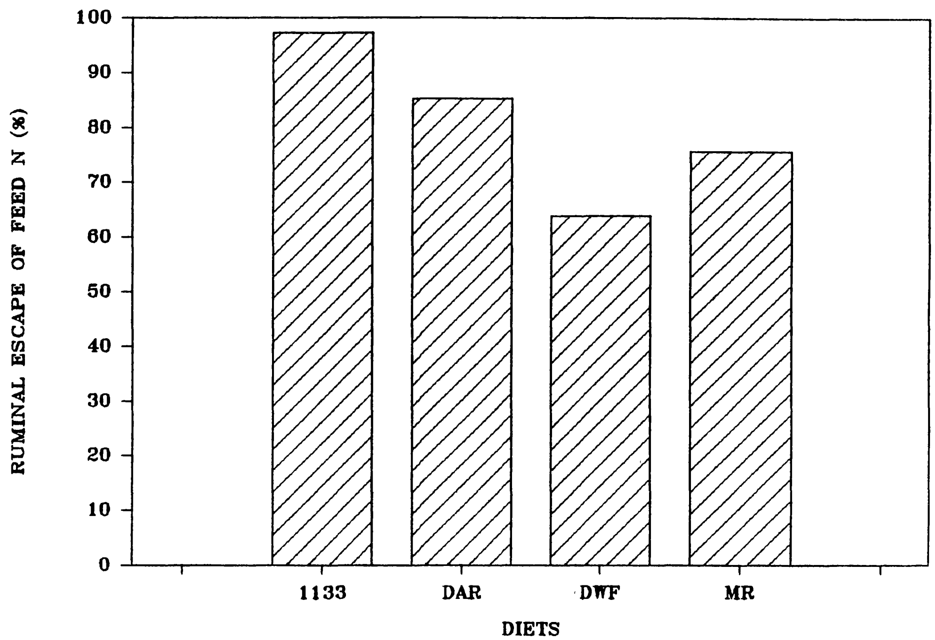

Figure 7. Percentage of Feed N Reaching the Duodenum

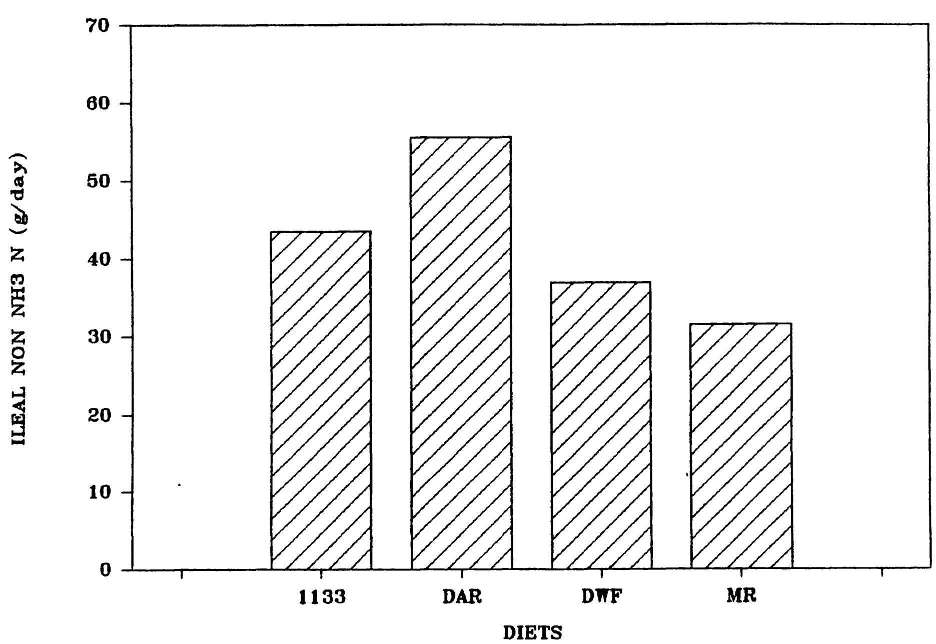

Figure 8. Non-Ammonia N Flow to the Ileum (g/d)

TABLE VIII

EFFECT OF SORGHUM GRAIN VARIETY ON DIGESTIBILITY THROUGH THE ILEUM

Item	1133	Dar	Dwf	Mr	SE
Leaving Ileum (g/day)					
Chyme (l/day)	11.4	13.4	9.6	9.9	2.47
Chyme pH	6.96	6.80	6.68	6.65	.148
Organic matter	1542	1779	1370	1558	118.2
Starch	425.0	543.9	475.2	665.7	81.17
Acid detergent fiber[a]	446.1	439.6	278.3	285.4	24.42
Tannin(cat.eq/day)[ab]	8.94	16.30	1.82	6.48	1.40
Total N[cde]	44.3	56.6	37.6	32.1	3.61
Ammonia N[efg]	0.82	1.08	0.70	0.65	.073
Non-ammonia N[cde]	43.5	55.5	36.9	31.5	3.55
Digestibility through the ileum (%)					
Organic matter	64.0	58.3	68.4	63.7	2.72
Starch[h]	85.0	81.0	84.7	76.2	2.82
Acid detergent fiber[i]	11.7	6.6	25.7	27.2	6.14
Tannin	83.8	76.4			220.38
Nitrogen,% total N based on:					
Total ileal N[i]	54.2	45.2	63.7	63.0	3.79
Ileal non-ammonia N[i]	55.0	46.2	64.4	63.8	3.74
Ileal digestibility (% of total digestion)					
Organic matter	90.0	86.6	92.0	84.9	3.60
Starch[h]	92.4	90.1	93.1	83.6	2.85
Total ileal N	103.1	96.7	93.6	100.2	4.46
Ileal non-ammonia N	103.1	97.1	93.6	100.2	4.34

[a]Bird resistant vs non-bird resistant varieties (P<.01).
[b]Waxy vs normal (P<.01).
[c]Interaction (P<.05).
[d]1133 vs Dar (P<.10).
[e]Dar vs Mr (P<.01).
[f]Interaction (P<.10).
[g]1133 vs Dar (P<.05).
[h]Waxy vs normal varieties (P<.10).
[i]Bird resistant vs non-bird resistant varieties (P<.05).

resistant sorghum grain. Increased N flow may be caused by tannin binding of feed or endogenous N or decreased feed protein solubility (Chibber et al., 1978; Hibberd et al., 1985). Nitrogen digestibility through the ileum (Figure 9), expressed either as total N or non-NH_3 N, was depressed for bird resistant diets ($P<.05$). Within bird resistant varieties waxy 1133 appeared to yield a greater digestion than Dar.

Organic matter digestion through the ileum was slightly greater ($P<.15$) for waxy (1133 and Dwf) than normal varieties (Dar and Mr). Starch digestion through the ileum (Figure 10) was greater ($P<.10$) for varieties with waxy endosperm than those with normal endosperm. Organic matter ($P<.20$) and starch ($P<.10$) from waxy varieties tended to be degraded (% total digestion) before the large intestine to a greater extent than for normal varieties. Within non-bird resistant varieties, starch in Dwf (waxy) appeared to be degraded before the large intestine to a greater extent than starch in Mr. Greater OM and starch digestion of varieties with waxy endosperm may be due to amylopectin availability to enzymatic and microbial attack (French, 1973) and perhaps an increased solubility of the protein matrix surrounding the starch granules (Lichtenwalner et al., 1978). Nitrogen digestion (% total digestion), however, was not significantly increased with waxy varieties

Intestinal Digestion. Digestion in the small and large intestines was not significantly influenced by treatment (Table IX); however, several important trends were present which may become more important at higher levels of feed intake. Starch digestion in the small intestine (% of starch entry) appeared to be higher for waxy grains within each tannin grouping (Figure 11). The small intestine appeared to be a more

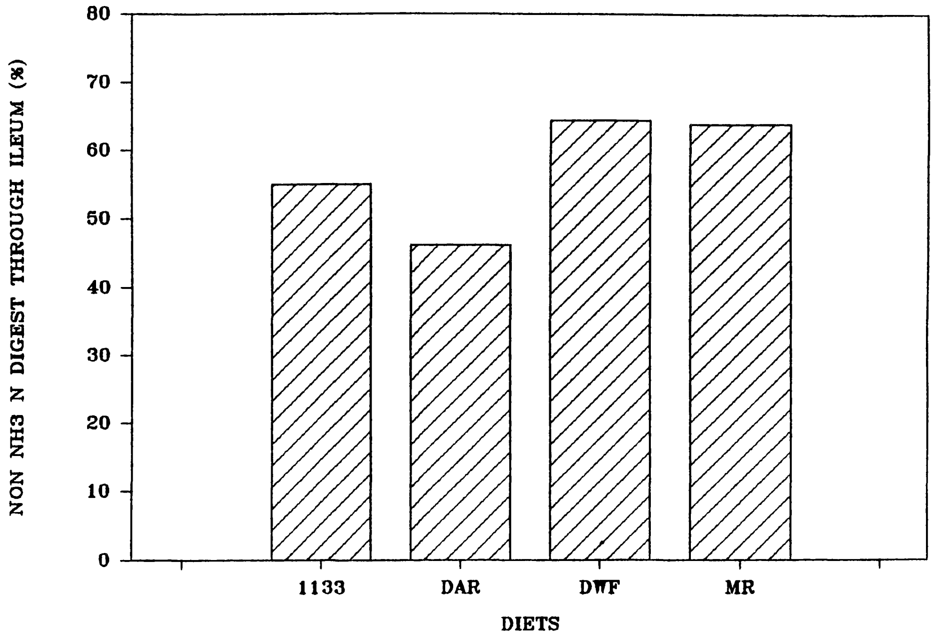

Figure 9. Non-Ammonia N Digestibility Through the Ileum

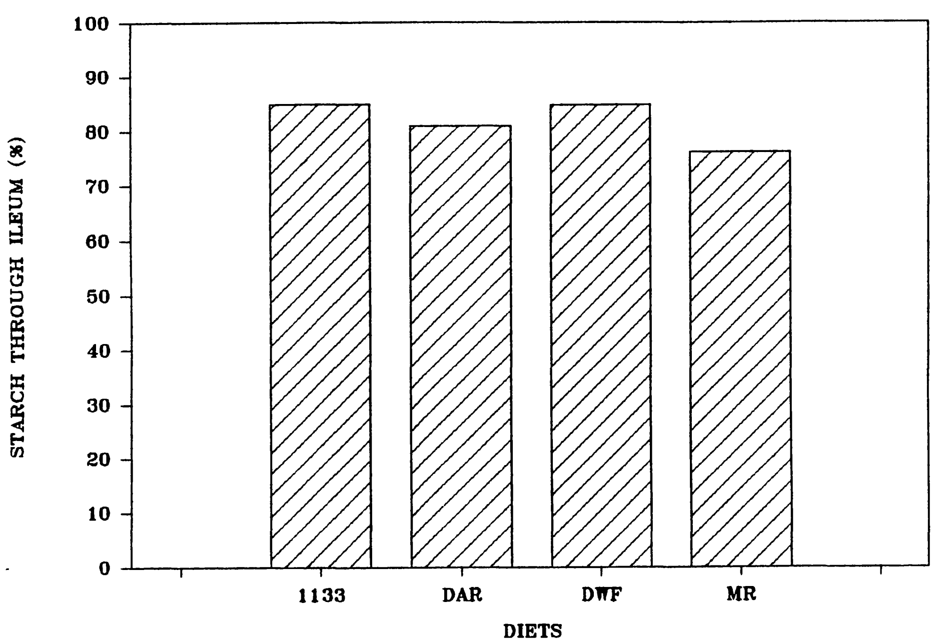

Figure 10. Starch Digestibility Through the Ileum

TABLE IX

EFFECT OF SORGHUM GRAIN VARIETY ON SMALL AND LARGE INTESTINAL NUTRIENT DIGESTION

Item	1133	Dar	Dwf	Mr	SE
Digestibility in the small intestine (% of entry)					
Organic matter	41.0	28.7	43.2	37.4	6.17
Starch	36.6	24.5	41.5	32.2	8.32
Total N	62.6	51.6	64.1	67.7	4.65
Non-ammonia N	61.6	49.8	62.7	66.8	4.72
Digestibility in the small intestine (% of intake)					
Organic matter	24.6	17.5	24.0	20.0	4.37
Starch	7.6	5.8	10.6	7.5	2.74
Digestibility in the large intestine (% of entry)					
Organic matter	19.4	21.2	23.4	24.8	8.58
Starch	51.1	46.0	53.2	57.2	14.76
Acid detergent fiber	11.7	11.1	17.6	6.0	6.56
Total N	-1.8	3.0	12.2	-0.3	4.76
Non-ammonia N	-1.9	2.8	12.7	-0.3	4.83
Digestibility in the large intestine (% of intake)					
Organic matter	7.0	9.0	7.0	10.5	2.69
Starch	6.9	8.8	6.8	14.2	2.54
Acid detergent fiber	10.8	11.0	12.8	7.8	5.44

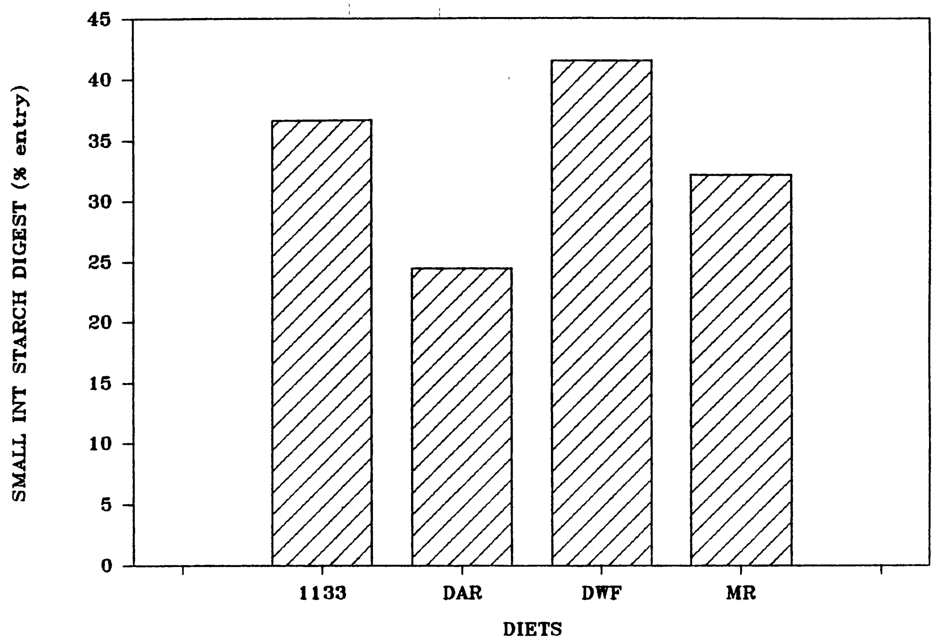

Figure 11. Starch Digestibility in the Small Intestine

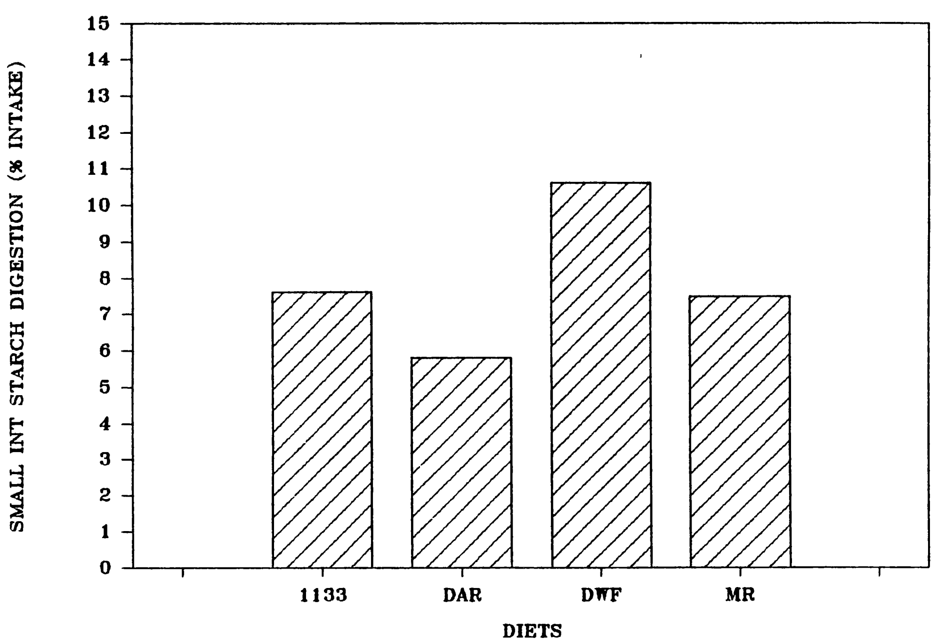

Figure 12. Starch Disappearance in the Small Intestine

important site of starch digestion (% of intake) for waxy varieties (Figure 12).

Non-NH_3 N digestion (% of entry) tended to be depressed for bird resistant varieties ($P<.15$). Within bird resistant types, Dar tended to have more depressed non-NH_3 N digestion in the small intestine than 1133 (Figure 13). Non-NH_3 N digestion in the small intestine was significantly ($P<.01$) correlated ($r=.94$) to starch digestion in the small intestine. Seckinger and Wolf (1973) proposed that the protein matrix surrounding the starch granules may limit enzymatic degradation. The strong correlation between starch and non-NH3 N digestion in the small intestine supports this theory.

Starch digestibility in the large intestine (% of intake) illustrates the importance of the large intestine as a site of fermentation (Figure 14). The large intestine tended to be a more important ($P<.15$) site of starch digestion for normal varieties. Moreover, within non-bird resistant varieties, the large intestine appeared to be a more important site of starch digestion for Mr (14.2%) than Dwf (6.8%). The large intestine has been suggested by Hibberd et al. (1985) as an important site of sorghum grain starch digestion. The large intestine appears to have the ability to compensate for poor starch digestion anterior to the large intestine (Table X). Based on data collected by Orskov et al. (1970) and Mason et al. (1977) one would anticipate increased N excretion with Mr in this case; however, no such increase was noted. Hibberd et al. (1985) reported large quantities of starch to be fermented in the large intestine without affecting N excretion. The factors responsible for increased fecal N excretion in association with starch fermentation in the large intestine are not

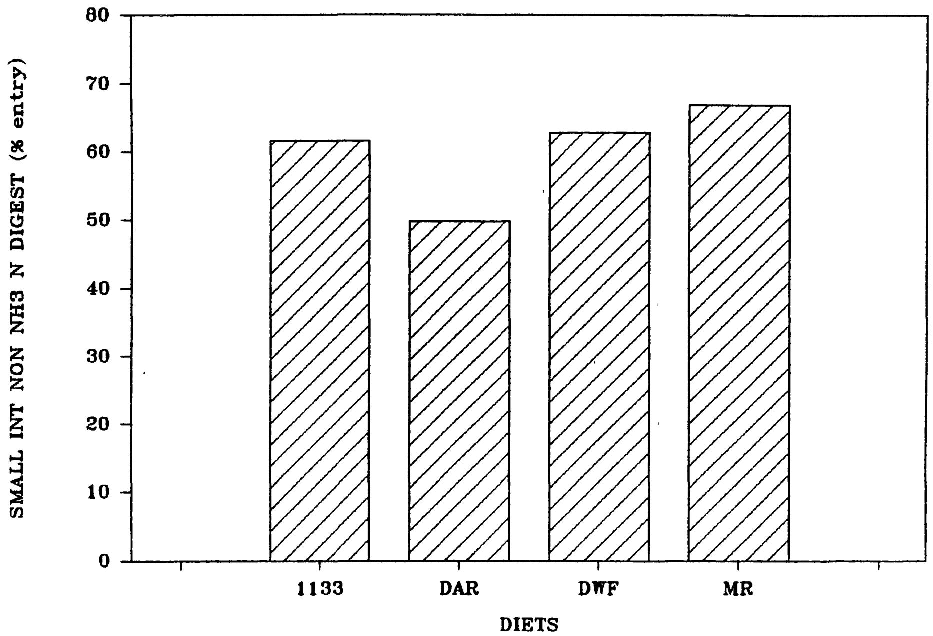

Figure 13. Non-Ammonia N Digestibility in the Small Intestine

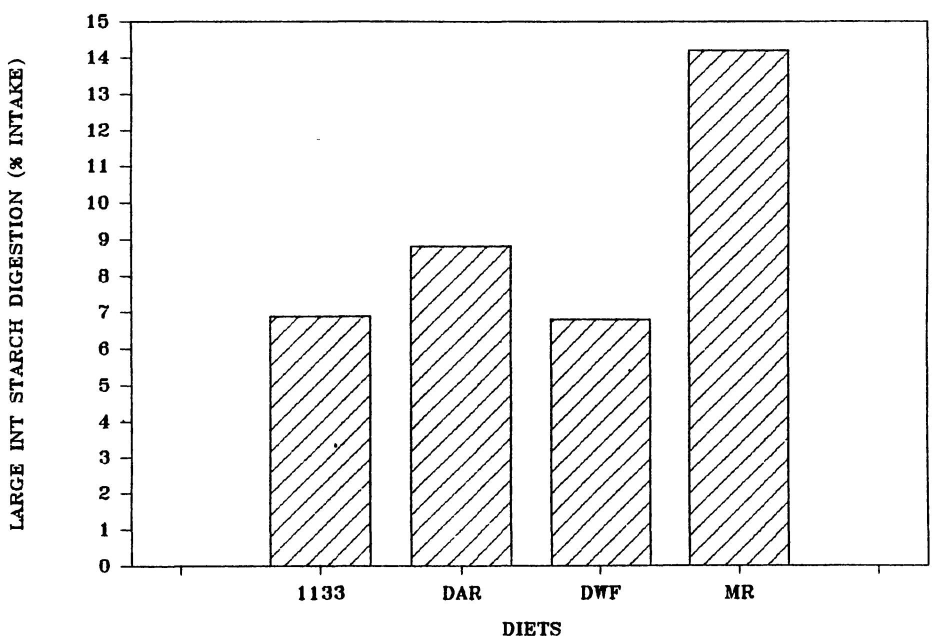

Figure 14. Starch Disappearance in the Large Intestine

TABLE X

EFFECT OF SORGHUM GRAIN VARIETY ON STARCH, ORGANIC MATTER AND NITROGEN DISAPPEARANCE FROM THE RUMEN, SMALL AND LARGE INTESTINES

Item	1133	Dar	Dwf	Mr	SE
Disappearance (g/day) Rumen					
Organic matter (corrected)	2162	2257	2460	2394	151.4
Starch[abc]	2185	2153	2280	1920	71.2
Small intestine					
Organic matter	1053.2	745.6	1046.4	860.2	192.79
Starch	215.8	167.7	329.7	209.9	82.48
Total N	74.3	63.1	67.9	66.6	6.58
Non ammonia N	69.8	57.6	62.7	62.6	6.15
Large intestine					
Organic matter	299.8	386.1	309.6	449.9	116.90
Starch	194.9	251.1	212.6	397.5	75.73

[a]Interaction (P<.10).
[b]Dwf vs Mr (P<.05).
[c]Dar vs Mr (p,.10).

clear. Further study is needed to determine why the large intestine appears to react atypically to sorghum fermentation. Perhaps starch infused into the ileum is more available for fermentation than is starch present in the grain that has passed through the digestive tract. Kim and Owens (1985) suggested grain particle size as a factor limiting starch digestion. Protein shielding of grain starch may also reduce the availability of starch that has passed through the digestive tract to fermentation in the large intestine.

The sorghum grain varieties tested differed in site and extent of nutrient digestion. Ruminal starch digestion tended to be greater for bird resistant varieties (Figure 15). Further study is needed to determine the factors responsible for increased ruminal starch digestion noted in this study for bird resistant varieties. All in vitro data suggests ruminal starch digestion of bird resistant sorghum grains should be depressed. Tannins appear to play an important role in altering site and extent of N digestion. Several theories exist to explain depressed N digestion (Tagari et al., 1965; Tamir and Alumot, 1969; Singh and Arora, 1980); however, assay procedures have made it difficult to determine the fate of tannins as they pass through the digestive tract. The presence of a waxy endosperm appears to alleviate to some degree the problems associated with the bird resistant characteristic (Figure 15). Further study is needed to determine the characteristics of waxy grains responsible for this improvement. Factors regulating large intestinal fermentation of sorghum starch are not clearly understood. Future studies may need to place more emphasis on the large intestine as a digestive site. The differences between the site and extent of nutrient digestion that exist among the sorghum grain

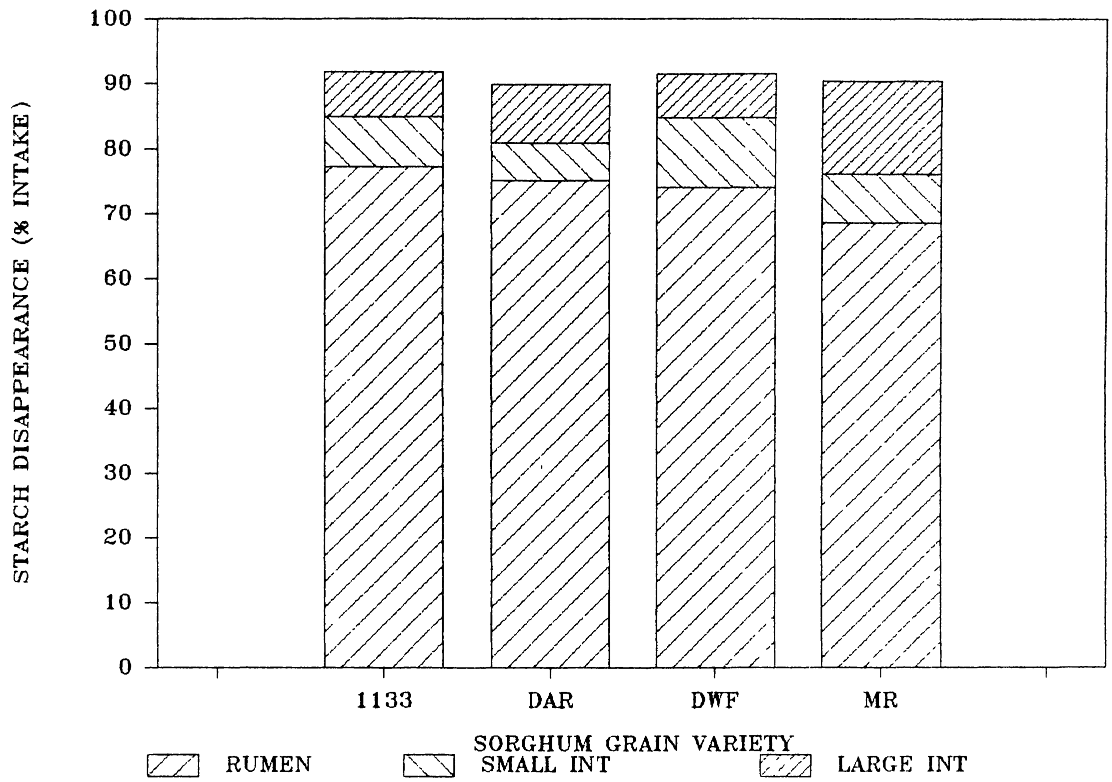

Figure 15. Site and Extent of Starch Digestion

varieties tested may be expected to result in differences in animal performance. Future studies should attempt to correlate differences between the site and extent of nutrient digestion with animal performance data.

CHAPTER IV

EFFECT OF ALTERING THE RATIO OF DRY ROLLED CORN TO HIGH MOISTURE HARVESTED SORGHUM GRAIN ON SITE AND EXTENT OF DIGESTION IN HEIFERS

ABSTRACT

Dry rolled corn (DRC) and high moisture harvested sorghum grain (HMS) were fed in diets of 100% DRC, 75:25, 50:50, 25:75 and 100% HMS to determine their effect on site and extent of nutrient digestion. Diets were fed at 2 % of body weight (dry basis) in a 5x5 Latin square using Angus-Hereford heifers (315 kg) equipped with ruminal, duodenal and ileal T-type cannulae. Total tract organic matter (OM), acid detergent fiber (ADF), nitrogen (N) ($P<.05$) and starch ($P<.10$) digestibilities declined linearly as HMS replaced DRC. Chyme flow (l/d) through the duodenum increased ($P<.01$) and ruminal OM disappearance, corrected for microbial OM, tended to decline linearly ($P<.10$) with added HMS. Ruminal ADF disappearance decreased quadratically ($P<.05$) with more HMS. Microbial efficiency (g microbial protein/kg OM truly fermented in the rumen) increased linearly ($P<.05$) with HMS. Digestion in the small intestine was not significantly influenced by altering the ratio of DRC:HMS. Digestion in the large intestine was affected much the same as ruminal digestion with OM ($P<.06$), starch ($P<.05$) and ADF ($P<.05$) disappearance decreasing linearly as HMS replaced DRC . Altering the

ratio of DRC to HMS had a greater effect on sites of fermentation than sites of enzymatic digestion. Changing the ratio of DRC to HMS appears to alter nutrient digestibility and site of digestion.

Introduction

High moisture sorghum grain has become a more important energy source for feedlot diets as the cost of grain processing has risen and irrigated corn production has declined. Blending of high moisture and dry grains does occur, but price rather than digestibility or cattle performance dictates the ratio between grain types. Little work has been conducted to determine the effect of blending dry and high moisture grains on site and extent of nutrient digestibility and animal performance.

Teeter et al. (1979) blended dry rolled corn (14%) and high moisture corn (27%) in a 50%:50% mixture and noted improved performance on the blend, although nutrient digestibility was not increased. Brandt et al. (1984) compared different corn blends and found improved feed efficiency and starch digestibility as the level of high moisture corn increased.

No work has been reported using blends of dry rolled corn and high moisture harvested sorghum. A combination of highly fermentable high moisture sorghum and dry rolled corn may maximize both digestion in the rumen and small intestine. Additional information on different corn-sorghum blends is needed. The objectives of this study; therefore, were to determine the effects of altering the ratio of dry rolled corn to high moisture harvested sorghum grain on: 1) chemical composition and in vitro gas production, 2) site and extent of starch digestion and 3) extent of feed protein escape to the small intestine in beef cattle.

Materials and Methods

Five diets (Table XI) were created using commercially obtained high moisture harvested sorghum grain (HMS) and coarsely dry rolled corn (DRC). Genetic background and geographic origin of HMS were known (70% DM, heteroyellow). Blends of DRC:HMS were 100% DRC, 75:25, 50:50, 25:75 and 100% HMS, denoted as 0, 25, 50, 75 and 100. Initial analysis of the corn indicated urea could not be used as the only source of supplemental nitrogen (N); therefore, soybean meal was included at equal levels (5.2% DM) for all diets, and urea was used in an attempt to balance diets for crude protein. Chromic oxide was included at .2 % of the diet (DM) as an indigestible marker to estimate digestibility coefficients. All blends and grain samples were stored at -20 C prior to feeding and analysis.

Laboratory Phase

Grain and diet samples were ground through a 20 mesh (1 mm) screen in a laboratory Wiley mill prior to chemical analysis and a 1 mm screen in a Udy mill prior to starch analysis. Dry ice was used to facilitate grinding of wet samples. Grain and blend samples were analyzed for: dry matter (DM) by toluene distillation (A.O.A.C., 1975), starch as α-linked glucose (MacRae and Armstrong, 1968), organic matter (OM, A.O.A.C., 1975), acid detergent fiber (ADF, Goering and Van Soest, 1970) and crude protein (N x 6.25) by macro kjeldahl (A.O.A.C., 1975). Grain and diet samples were further analyzed for pepsin insoluble nitrogen (PIN) as described by Goering and Van Soest (1970) and sodium chloride (NaCl) soluble protein as described by Waldo and Goering (1979).

In vitro gas production (IVGP) procedures described by Hibberd et al. (1982a) were used to estimate the availability of grain starch to enzymatic attack. IVGP data were analyzed to determine differences in the total amount of CO_2 produced per g of DM at 6 and 12 h of incubation.

Animal Phase

Diets (Table XI) were fed to 5 Hereford-Angus heifers (315 kg) equipped with ruminal, duodenal (4 cm distal to pylorus) and ileal (20 cm cranial to the ileo-cecal junction) T-type cannulae. Heifers were fed twice daily to total 2 % of body weight (DM basis) in a 5x5 Latin square. Experimental periods were 10 days in length. Days 1 through 7 allowed animals to adapt to new diets and days 8 through 10 were used for digesta and fecal sampling. During the sampling period, heifers were fed equal portions at 0800 and 2000 h and sampled at 1000, 1400 and 1800 h. Feed samples were collected on days 7 through 9 and composited across days. Ruminal fluid for ammonia (NH_3) determination was collected at each of 3 times on the last day of each period. Rumen fluid samples were acidified with 3.3 ml of 36 N H_2SO_4 per 1000 ml of fluid immediately after pH determination.

Ruminal fluid (2000 ml/heifer) used to estimate bacterial nucleic acid-N, total N and OM, was collected from each heifer on the last day of sampling during periods 1 and 5 at 1400 hours. Equal volumes (500 ml) of ruminal fluid from each heifer were composited within each period on the day of collection. Bacteria were isolated from the rumen fluid 1 day after collection by differential centrifugation (Weakley, 1983). Isolated bacteria were freeze dried and ground with a mortar and pestle prior to analysis.

Ruminal (1000 ml), digesta (500 ml duodenal and 250 ml ileal fluid collected per time) and fecal grab samples were composited across time and day within animal for each period after pH determination and stored at 5 C until the end of each period. Subsamples of ruminal (NH_3), duodenal and ileal fluids and fecal matter were obtained at the end of each period and stored at -20 C. Digesta and fecal samples were dried using a lyophilizer prior to grinding through a 20 mesh (1 mm) screen in a laboratory Wiley mill or a 1 mm screen in a Udy mill (to analyze for starch content) and chemical analyses.

Feed, ruminal (NH_3 and bacteria), duodenal, ileal and fecal samples were analyzed for all components described earlier with the addition of: OM (A.O.A.C., 1975), ammonia (NH_3) by magnesium oxide distillation (A.O.A.C., 1975), total purines (Zinn and Owens, 1982a) and chromic oxide (Fenton and Fenton, 1979).

Partial digestion coefficients and amounts of different nutrients presented to and disappearing from segments of the digestive tract were determined by chromic oxide ratios. Microbial N reaching the duodenum was calculated as duodenal nucleic acid N divided by the ratio of total microbial nucleic acid N to total microbial N. In period 1, the ratio of microbial nucleic acid N to microbial N was .24, and in period five .22. In periods 2, 3 and 4 the average ratio of periods 1 and 5 was used (.23). Feed N (plus endogenous N) reaching the duodenum was calculated as total duodenal N minus NH_3-N and microbial N. Organic matter reaching the duodenum was corrected for microbial OM based on a determined microbial crude protein content of 51.02% and ash content of 24.00%. Corrected duodenal organic matter was used to calculate true microbial efficiency (g microbial N/kg OM truly fermented in the rumen) and corrected ruminal organic matter digestibility.

Between periods 3 and 4 the ileal cannulae of heifer 227 began to seal; therefore, during periods 4 and 5, while consuming blends 50 and 0 respectively, no ileal samples could be obtained. As a result two cells of ileal data were missing within a single column.

Statistical Analysis

Data obtained from IVGP can be described by the following model: $Y_{ijk} = \mu + B_i + R_j + E_{ijk}$ where Y_{ijk} is the observed value, B is the blend and R is the run. The components μ, B_i and R_j were treated as fixed effects of all records of blend i and run j. Random error effects, E_{ijk} were specific for each observation.

Data from the animal phase (5x5 Latin square) can be described by the following model: $Y_{ijk} = \mu + B_i + P_j + H_k + E_{ijk}$ where Y_{ijk} is the observed value, B is the blend, P is the period and H is the heifer. The components μ, B_i, P_j and H_k were treated as fixed effects of all records of blend i, period j and animal k. Random error effects, E_{ijk}, were specific for each observation.

Estimated treatment (blend) means were obtained using least squares analysis. The response to the DRC:HMS ratio was determined using linear, quadratic, cubic and quartic orthogonal contrasts (Table XII) (Steel and Torrie, 1980).

TABLE XI

INGREDIENT COMPOSITION OF EXPERIMENTAL DIETS

Ingredient (% DM)	DRC:HMS 0	25	50	75	100
Dry rolled corn	83.2	62.6	41.8	20.9	0.0
High moisture sorghum	0.0	20.8	41.8	62.7	83.8
Cottonseed hulls			8.0		
Soybean meal			5.2		
Urea	1.0	.87	.76	.65	.53
Supplement					
Sodium sulfate	.17	.14	.13	.11	.09
Dical phosphate			.44		
Calcium carbonate			.93		
Potassium chloride			.57		
Chromic oxide			.20		
Vitamin A (IU/kg)			2200		

TABLE XII

ORTHOGONAL POLYNOMIALS

Polynomial	DRC:HMS 0	25	50	75	100
Linear	-2	-1	0	1	2
Quadratic	2	-1	-2	-1	2
Cubic	-1	2	0	-2	1
Quartic	1	-4	6	-4	1

Results and Discussion

Laboratory phase

Crude protein ($P<.05$), starch ($P<.10$) and ADF ($P<.01$) content of the complete diets decreased quadratically with less DRC (Table XIII). Sodium chloride soluble protein increased cubicly ($P<.05$) for both the grain mix and the complete mixed feeds as the level of HMS was increased. Hibberd (1982) reported an increased level of NaCl soluble protein in association with reconstitution of sorghum grains. Pepsin insoluble N decreased linearly ($P<.01$) as the level of HMS increased in the grains. Pepsin insoluble N decreased quartically ($P<.01$) in the complete mixed feeds as the level of HMS increased. Hibberd (1982) and Walker and Lictenwalner (1977) reported PIN to decrease due to reconstitution. Decreased PIN has been reported by Aguirre et al. (1984a) with high moisture harvested and reconstituted corn.

A linear increase in the amount of gas produced in vitro (Table XIV) occurred at both 6 and 12 h of incubation as HMS replaced DRC ($P<.01$). High moisture grains have been previously reported to be more digestible than dry rolled grains (Neuhaus and Totusek, 1971; Aguirre et al., 1984b).

Animal phase

Organic matter ($P<.05$) (Figure 16), starch ($P<.10$), ADF ($P<.01$) (Figure 17) and N based on total fecal N ($P<.01$) or fecal non-NH_3 N ($P<.05$) digestibilities in the total tract (Table XV) decreased linearly with more HMS. Total tract OM (50, 79.5% to 75, 74.6%), starch (50, 93.0% to 75, 89.5%) and N (50, 97.1% to 75, 96.6%) digestibilities

TABLE XIII

CHEMICAL COMPOSITION OF DRC, HMS AND COMPLETE MIXED FEEDS (DRY BASIS)

	DRC:HMS					
Item (%)	0	25	50	75	100	SE
Grain						
Crude protein	9.5				9.8	.04
Starch	78.5				84.0	2.33
Ash	1.33				1.32	.088
Acid Detergent Fiber	3.30				3.27	.069
NaCl soluble N	13.9	23.3	36.8	50.7	61.8	.53
Pepsin insouble N	14.2	13.2	10.5	8.7	6.7	.33
Feed						
Crude protein	12.8	14.0	13.8	13.4	12.9	.16
Starch	66.5	65.7	65.8	66.5	71.0	1.68
Ash	4.04	4.55	4.40	4.41	4.65	.065
Acid Detergent Fiber	10.9	8.5	7.8	8.5	8.5	.20
NaCl soluble N	37.6	39.9	43.7	52.8	51.4	1.10
Pepsin insoluble N	12.3	11.1	9.2	10.2	8.8	.15

TABLE XIV

IN VITRO GAS PRODUCTION OF DRC AND HMS GRAIN BLENDS

	DRC:HMS					
Item	0	25	50	75	100	SE
IVGP (ml gas/g DM)						
6 h*	56.6	58.8	63.2	63.0	66.7	1.31
12 h*	85.0	85.6	92.2	94.7	101.9	1.82

*Linear effect (P<.01).

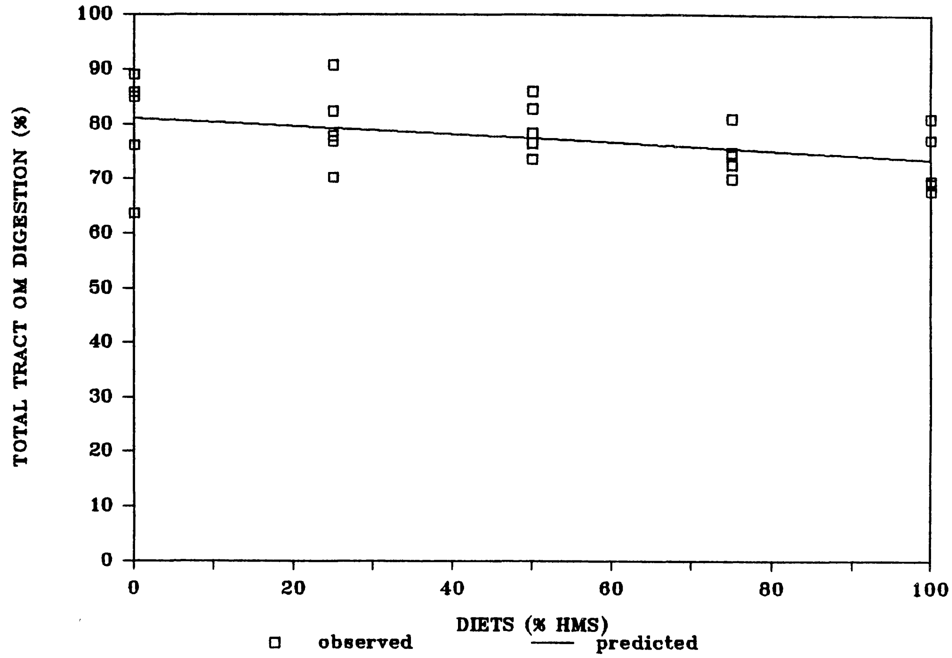

Figure 16. Total Tract Organic Matter Digestibility

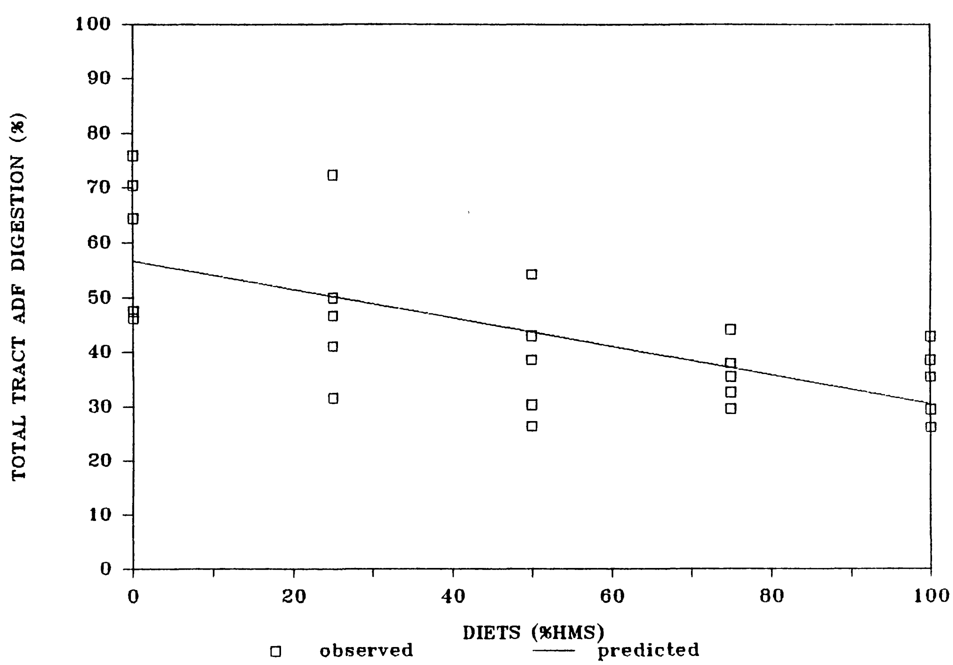

Figure 17. Total Tract ADF Digestibility

TABLE XV

EFFECT OF ALTERING THE DRC:HMS RATIO ON TOTAL TRACT NUTRIENT DIGESTION

Item	DRC:HMS 0	25	50	75	100	SE
Fecal output						
(kg/day)[a]	4.85	5.02	4.91	6.34	6.20	.526
Fecal pH	5.85	5.94	5.83	5.81	5.84	.078
Feces (g/day)						
Organic matter[b]	1194	1208	1234	1536	1626	124.8
Starch	312.4	309.9	289.8	439.6	530.1	82.33
ADF[a]	264.3	273.9	302.4	344.5	354.0	22.02
Total N[a]	36.5	39.0	38.6	45.4	46.0	2.22
Ammonia N	1.23	1.24	1.47	1.36	1.57	.119
Non-ammonia N[a]	35.2	37.8	37.2	44.0	44.4	2.20
Total tract digestibility (%)						
Organic matter[b]	80.0	79.6	79.5	74.6	73.0	2.09
Starch	92.4	92.4	93.0	89.5	88.2	1.97
ADF[a]	60.9	48.3	38.3	35.9	34.4	3.92
Total feed N based on:						
Total fecal N[a]	71.5	72.0	71.3	66.6	64.7	1.65
Fecal non NH_3 N[a]	72.5	72.8	72.4	67.6	65.9	1.65

[a]Linear (P<.01).
[b]Linear (P<.05).

appeared to remain relatively constant through blend 50, suggesting that low levels of HMS may not depress digestion; however, quadratic effects for all variables were far from significant (P>.20). Brandt et al. (1984) reported total tract starch digestion increased linearly as high moisture corn replaced dry rolled corn. Sorghum grain is usually less digestible than corn (Waldo, 1973). Therefore, comparisons between DRC:HMS blends and high moisture corn:dry rolled corn blends are probably not valid due to differences that exist between sorghum and corn grain. Brandt et al. (1984) reported a linear increase in ADF digestion as high moisture corn replaced dry rolled corn in the diet. Explanation for this difference is probably related to chemical and/or physical differences that exist between sorghum and corn grain. Nitrogen digestion may have been depressed by the HMS because of lower degradability of sorghum protein (Spicer et al., 1983).

Ruminal Digestion. Ruminal pH (P<.05) and duodenal chyme flow (P<.01) (Figure 18) increased linearly (Table XVI) with more HMS. One would have anticipated declining ruminal pH based on IVGP results with more HMS. Increasing chyme flow suggests increasing ruminal liquid dilution rate. Increased chyme flow has been noted with reconstituted sorghum grain (Hibberd et al., 1985). Increased ruminal pH and duodenal chyme flow suggests that salivary flow may have been increased with HMS. Galyean et al. (1979) suggested that chyme flow may increase due to greater levels of highly fermentable substrate in the rumen. Ruminal pH, OM and starch digestion coefficients do not support the existence of a greater quantity of highly fermentable substrate with the inclusion of HMS. In vitro gas production data, however, would suggest that blends containing increasing levels of HMS do have greater amounts of highly available substrate.

Ruminal NH_3-N concentration tended to increase and OM disappearance (%) tended to decrease linearly (P<.10) as greater amounts of HMS were included in the blend (Table XVI). Declining ruminal OM digestion associated with increased levels of HMS may be responsible for the simultaneously occuring linear increase in ruminal NH_3 concentration. Low levels of HMS (blends 0, 25 and 50) appeared to have little effect on ruminal OM disappearance.

Starch digestibility in the rumen was apparently not affected by altering the level of HMS. One may have anticipated increased ruminal starch disappearance based on data collected with other processing methods (Hibberd, 1982). However, increasing starch intake as the level of HMS increased makes ruminal starch disappearance (%) hard to interpret. Therefore, the actual amount of starch (g/d) that disappeared in the rumen (Table XIX) may be a better indication of ruminal starch digestion than the digestibility coefficients. A quadratic response (P<.05) of starch disappearance (g/d) and ADF digestibility in the rumen suggests associative effects. The factors responsible for a quadratic response to elevating HMS levels are not clear and need further study. Starch disappearance in the rumen declined through blend 75 (3316 g/day) before increasing with blend 100 (3709 g/day). Blend 0 (58.7%) and 25 (47.2%) appeared to have greater ruminal ADF disappearance than blend 100 (34.8%), 75 (33.6%) and 50 (27.5%). Perhaps blend 50 is more highly fermentable, in vivo, than other blends, making the rumen environment less favorable for ADF digestion (Goetsch et al., 1983). In vitro gas production data was poorly correlated to total tract (r = -.43; P<.16), and ruminal starch digestibility (r = 0.26; P<.42). Weak correlations suggest that IVGP did a poor job of estimating starch digestion in vivo. The apparent discrepancy between organic matter and starch digestion in the rumen is likely due to increasing starch intake with more HMS.

Ruminal total feed N and feed non-urea N disappearance (%) (Figure 19) tended to increase quadratically (P<.10) at a decreasing rate with higher levels of HMS. Total feed N disappearance in the rumen appeared to increase through blend 75 (55.5%) and then decrease dramatically at blend 100 (44.1). Ruminal N disappearance resulted in a quadratic decrease in escape of N from ruminal degradation (P<.10) (Figure 20) similar to starch disappearance (g/day) in the rumen. Other reports are not available to make a comparison and aid in the explanation of these findings. Salivary flow may have increased causing chyme flow and ruminal pH to increase and affected DRC and HMS proteins differently resulting in quadratic bypass and digestion of feed N (Cole et al., 1976b). Different combinations of DRC and HMS may also have altered the microbes ability to degrade protein (Bergen and Yokoyama, 1977).

The efficiency of microbial protein synthesis increased linearly (P<.05) as HMS replaced DRC in the blend (Figure 21). Increased microbial efficiency is the result of linearly increasing (P<.05) microbial N flow to the duodenum and linearly decreasing (P<.10) ruminal OM (corrected) disappearance. Hibberd (1982) reported an increase in microbial efficiency apparently caused by reconstitution of sorghum grain. However, ruminal OM disappearance and microbial N production were increased by reconstitution. Linearly increasing chyme flow (P<.01) and possibly increasing liquid dilution rate in association with

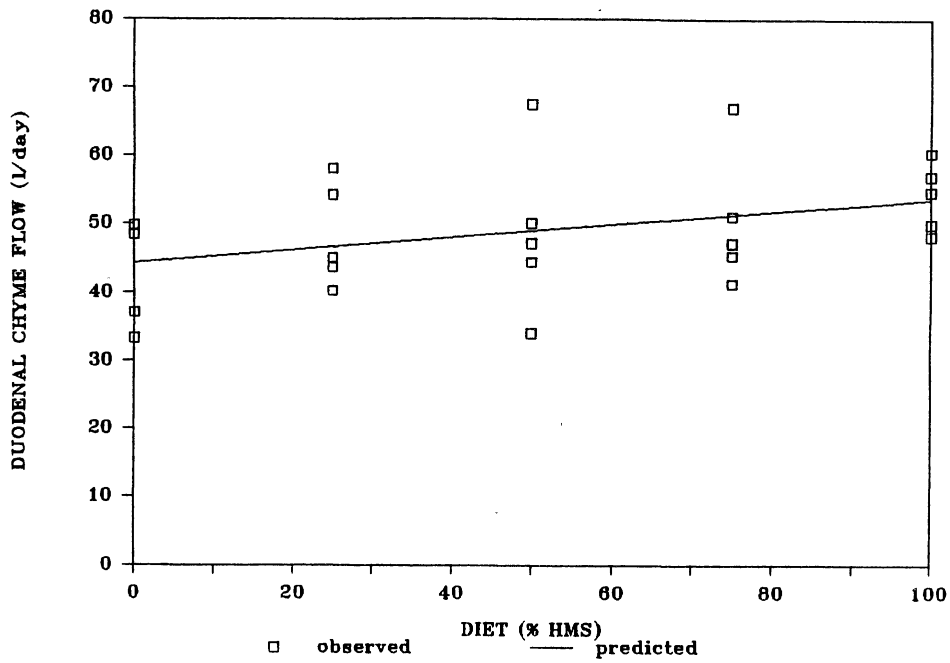

Figure 18. Chyme Flow to the Duodenum (l/d)

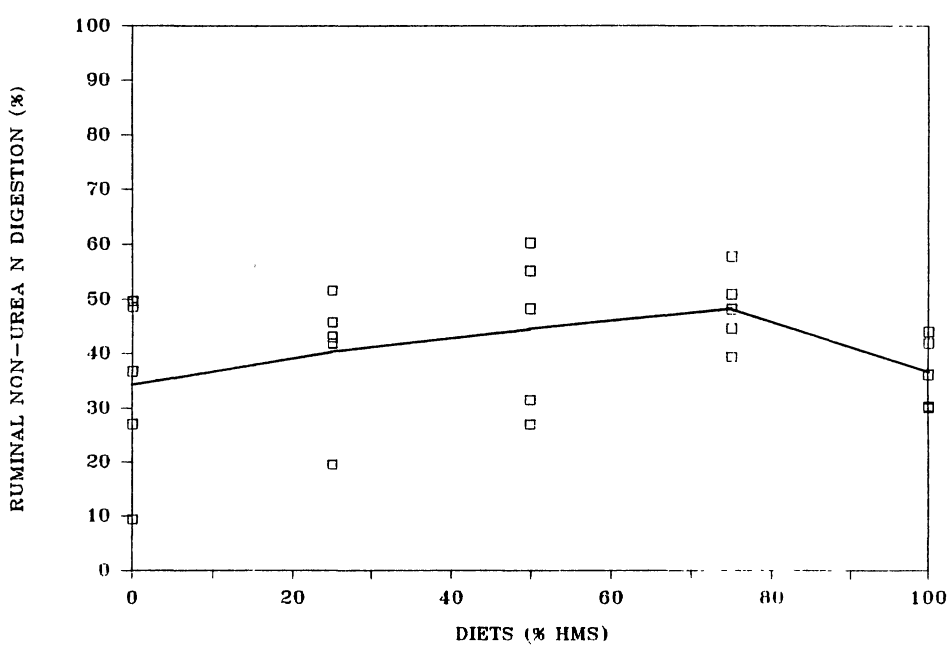

Figure 19. Non Urea N Digestibility in the Rumen

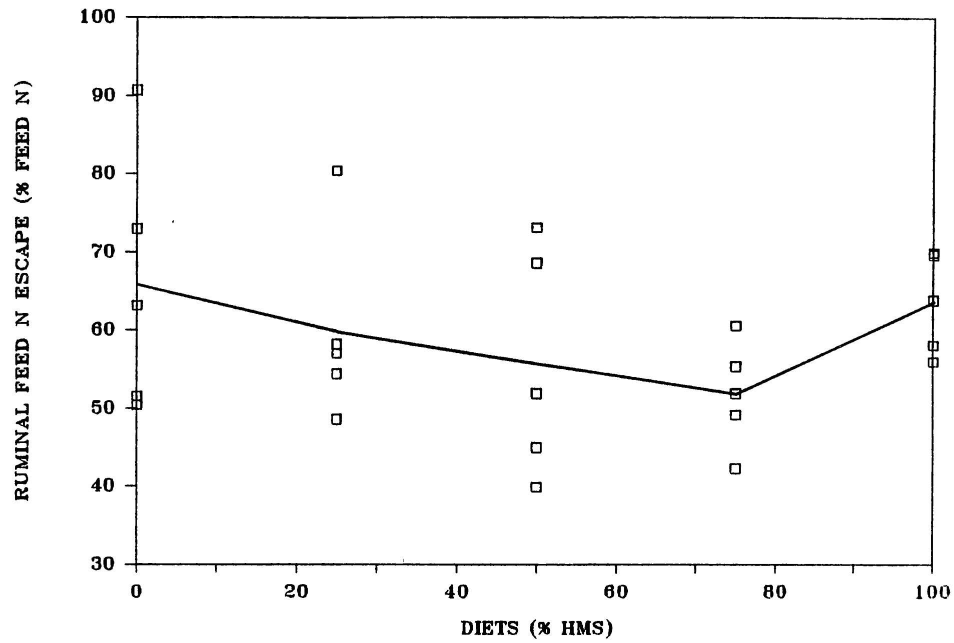

Figure 20. Percentage of Feed N Reaching the Duodenum

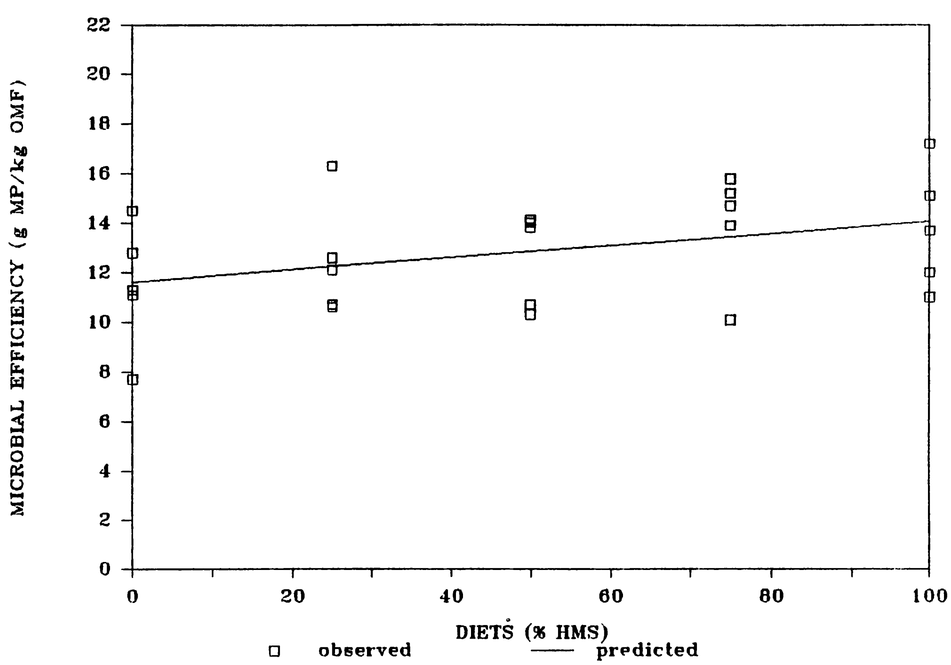

Figure 21. Efficiency of Microbial Protein Production

TABLE XVI

EFFECT OF ALTERING THE DRC:HMS RATIO ON RUMINAL NUTRIENT DIGESTION

	DRC:HMS					
Item	0	25	50	75	100	SE
Intake (g/day)						
Organic matter	5966	5927	6011	6040	6032	
Starch	4136	4079	4138	4204	4495	
ADF	675.8	529.7	490.3	537.8	539.9	
Total N	128.1	139.1	134.6	135.8	130.3	
Non-urea feed N	99.1	113.9	112.6	116.4	114.7	
Rumen environment						
pH[a]	5.84	6.03	6.05	6.06	6.14	.079
Ammonia N (mg/dl)	5.36	8.30	6.80	8.43	8.15	.914
Entering duodenum (g/day)						
Chyme (l/day)[b]	43.6	48.2	48.6	50.4	54.0	2.05
Chyme pH[c]	2.28	2.49	2.42	2.46	2.41	.040
Total Organic matter[a]	2219	2335	2329	2559	2628	142.6
Non-microbial organic matter	1780	1864	1845	2039	2124	138.1
Starch	594.5	708.7	661.4	887.6	785.4	104.74
ADF[a]	279.2	279.9	355.5	357.1	352.0	28.09
Total N	117.7	125.4	121.3	123.4	134.6	5.06
Ammonia N[b]	5.26	6.77	6.72	7.26	7.56	.230
Microbial N[a]	47.2	50.6	51.9	55.8	54.2	2.36
RNA N[a]	10.9	11.7	12.0	12.8	12.5	.54
Feed N	65.2	68.0	62.7	60.4	70.9	5.00
Rumen digestibility (%)						
Organic matter (corrected)	70.2	68.6	69.3	66.2	64.8	2.30
Starch	85.6	82.6	84.0	78.9	82.5	2.49
ADF[bc]	58.7	47.2	27.5	33.6	34.8	5.27
Total feed N	49.1	51.1	53.4	55.5	44.1	3.75
Non-urea feed N	34.2	40.2	44.3	48.1	36.4	4.55
Ruminal escape of feed N	65.8	59.7	55.7	51.9	63.5	4.55
Apparent microbial eff(gMP/kg OMF)[a]	13.0	14.2	14.3	16.0	15.9	.95
True microbial eff (gMP/kg OM truly fermented)[a]	11.5	12.5	12.6	13.9	13.8	.74

[a]Linear (P<.05).
[b]Linear (P<.01).
[c]Quadratic (P<.05).

elevating the level of HMS in the blend may be responsible for the observed linear response with microbial efficiency (Bergen et al., 1982).

Microbial efficiency was negatively correlated to ruminal starch disappearance ($r = -.69$; $P<.01$). Cole et al. (1976b) noted that microbial efficiency generally decreases as a ration contains greater amounts of rapidly fermentable substrate. A discrepancy exists with high moisture processing. Hibberd (1982) and Aguirre et al. (1984b) reported high moisture grains to increase microbial efficiency and starch digestion in the rumen. Based on ruminal nutrient digestion coefficients it is questionable whether increasing the level of HMS in the blend resulted in an increase in rapidly fermentable substrate for the rumen microbes.

Ileal Digestion. Nutrient digestibility through the ileum (Table XVII) was largely unaffected by altering the blend of HMS and DRC. Ileal chyme flow (l/d) was not significantly altered by treatment. Chyme flow (l/d) through the ileum was negatively correlated to organic matter disappearance ($r = -.63$; $P<.05$) and non-NH3 N disappearance ($r = -.56$; $P<.10$) in the small intestine, suggesting that the rate of chyme flow may have limited nutrient digestion in the small intestine for some blends.

Organic matter digestibility through the ileum was not significantly influenced by altering the DRC:HMS ratio and averaged 73.7% across all blends. Ileal starch disappearance was also not influenced by treatment (86.2%). Acid detergent fiber digestion through the ileum responded quadratically ($P<.05$) to altering the ratio of HMS to DRC. Blend 0 had the greatest ileal ADF digestibility (54.2%), while

TABLE XVII

EFFECT OF ALTERING THE DRC:HMS RATIO ON NUTRIENT DIGESTIBILITY THROUGH THE ILEUM

Item	DRC:HMS 0	25	50	75	100	SE[a]
Leaving ileum (g/day)						
Chyme (l/day)	11.8	10.6	10.8	12.4	12.0	.97
Chyme pH	6.76	6.62	6.83	6.63	6.88	.116
Organic matter	1599	1442	1509	1721	1622	173.6
Starch	594.7	488.4	520.2	678.3	623.9	116.06
ADF	311.7	284.3	333.1	315.4	302.3	24.20
Total N	37.6	39.0	37.8	42.4	39.4	2.78
Ammonia N	0.9	1.1	0.9	0.8	0.8	.14
Non-NH_3 N	36.7	37.9	36.9	41.6	38.6	2.70
Digestibility through the ileum (%)						
Organic matter	73.2	75.7	74.9	71.5	73.1	2.89
Starch	85.6	88.0	87.5	83.9	86.1	2.71
ADF[b]	54.2	46.3	31.3	41.4	44.0	4.34
Total ileal N	70.7	71.9	71.9	68.7	69.8	2.10
Ileal non-NH_3 N	71.3	72.7	72.6	69.4	70.3	2.04
Ileal digestibility (% of total disappearance)						
Organic matter	93.0	95.3	94.2	96.0	100.5	3.08
Starch	93.4	95.3	94.1	93.6	97.6	2.34
ADF	97.4	99.4	78.7	121.4	131.2	16.61
Total N	100.0	100.3	101.0	103.6	108.4	3.56
Non-ammonia N	99.6	100.2	100.4	102.9	107.3	3.38

[a]Standard errors presented are for blends 25, 75 and 100. Standard errors for blends 0 and 50 are approximately 20% higher due to missing cells in periods 4 and 5.
[b]Quadratic (P<.05).

blend 50 had the lowest ileal ADF digestibility (31.3%). Acid detergent fiber digestion through the ileum was probably an artifact of quadratic ruminal and limited small intestinal digestion. Nitrogen disappearance through the ileum based on total ileal N (70.6%) or non-NH_3 N (71.3%) was not altered by treatment.

Ileal OM and ADF disappearance (% of total digestion) tended to increase linearly ($P<.18$) with the replacement of DRC by HMS. Starch and N disappearance through the ileum (% of total digestion) showed no significant response to altering the DRC:HMS ratio. The similarity of nutrient digestion through the ileum, across all diets in combination with differences reported in the rumen suggests that the importance of the small intestine as a site of nutrient digestion was not equal for all blends.

Intestinal Digestion. The small intestine as a site of OM and N digestion tended, to compensate for ruminal decreased responses (Table XVIII). Organic matter disappearance in the small intestine (% of OM intake) appeared to increase with more HMS. Total N ($P<.20$) and non-NH_3 N ($P<.15$) digestion in the small intestine (% of N intake) responded quadratically in the opposite direction from ruminal N disappearance with increasing HMS. Blends 25 (51.1%), 50 (53.4%) and 75 (55.5%) appeared to have greater ruminal N digestion and lower N digestion in the small intestine (62.1, 62.4 and 59.6% of total N intake, respectively). Blends 0 (49.1%) and 100 (44.1%), on the other hand, appeared to have lower ruminal N digestion and higher N digestion in the small intestine (65.7% and 73.1% of total N intake respectively).

The small intestine was a much less important site of starch digestion (3.8% of starch intake) than the rumen (82.7% of starch intake). Therefore, the effects of the rumen overshadow the small intestine resulting in starch digestion through the ileum (% of intake) being only slightly greater in magnitude than ruminal starch digestibility (86.2% versus 82.7%).

Digestion in the small intestine (% of entry) was not influenced significantly by altering the ratio of DRC:HMS (Table XVIII). Organic matter (35.7% of entry) and starch (21.4% of entry) digestibilities in the small intestine were generally low (Figure 22 and 23). The small intestine may have a limited capacity to digest starch (Karr et al., 1966; Waldo, 1973; Armstrong and Smithard, 1979; Zinn and Owens, 1980). Amylase, maltase and isomaltase have been implicated as enzymes limiting starch digestion in the small intestine (Armstrong and Smithard, 1979). Recent work by Remillard and Johnson (1984) suggests that starch hydrolysis in the small intestine is not limited by in sufficient amylase secretion or depressed chyme pH. Kim and Owens (1985) implicate grain particle size as a major factor limiting starch digestion in the small intestine and total tract. Perhaps particle size differences existed in the current study due to moisture.

Fermentation in the large intestine responded significantly to altering the DRC:HMS ratio. Organic matter disappearance in the large intestine (% of entry) declined linearly ($P<.06$) as DRC was replaced by HMS. The negative OM disappearance value present for blend 100 may be due to excretion of microbial OM resulting from large amounts of microbial fermentation in the large intestine. Orskov et al. (1970), Mason et al. (1977) and Goetsch and Owens (1984) infused starch into the ileum and noted an increased OM content of feces associated with starch disappearance in the large intestine. Hibberd et al. (1985) noted that

TABLE XVIII

EFFECT OF ALTERING THE DRC:HMS RATIO ON NUTRIENT DIGESTION IN THE SMALL AND LARGE INTESTINES

	DRC:HMS					
Item	0	25	50	75	100	SE[a]
Digestibility in small intestine:						
% of entry						
Organic matter	34.2	38.7	33.6	33.1	38.7	5.05
Starch	13.4	32.6	13.8	24.6	22.6	10.04
Total N	68.6	68.1	68.1	65.6	70.6	2.90
Non-ammonia N	68.0	67.1	67.0	64.2	69.4	3.03
% of intake						
Organic matter	13.3	15.1	13.6	13.9	16.7	1.96
Starch	1.7	5.4	3.4	5.0	3.6	1.57
Total N	65.7	62.1	62.4	59.6	73.1	4.95
Non-ammonia N	62.2	58.0	58.1	54.9	67.8	4.86
Digestibility in the large intestine:						
% of entry						
Organic matter[b]	21.8	18.0	17.3	8.5	-5.1	8.52
Starch[c]	53.8	38.4	43.0	22.8	9.4	13.40
ADF[c]	7.1	4.6	9.5	-15.7	-27.4	11.34
Total N	-0.6	0.8	-3.2	-8.3	-25.2	10.63
Non-ammonia N	0.5	1.2	-1.5	-7.3	-23.1	10.33
% of intake						
Organic matter	5.7	3.9	4.7	3.1	-0.1	2.21
Starch	6.1	4.4	5.5	5.7	2.1	2.10
ADF	5.4	2.0	9.0	-5.4	-9.6	5.90

[a]Standard errors presented are for blends 25, 75 and 100. Standard errors for blends 0 and 50 are approximately 20% higher due to missing cells in periods 4 and 5.

[b]Linear (P<.06).

[c]Linear (P<.05).

fermentation of large quantities of sorghum starch in the large intestine resulted in no increase in OM content of feces. The large intestine appears to be a poorly understood site of nutrient digestion that needs further study to explain OM excretion associated with starch fermentation. A linear decrease ($P<.05$) noted in starch and ADF disappearance in the large intestine (% of entry) when HMS replaced DRC does not support the suggestion of excretion of microbial OM. Total N and non-NH_3 N disappearance in the large intestine tended to decline linearly ($P<.15$) as HMS replaced DRC. If microbial OM were responsible for linearly decreasing OM disappearance in the large intestine, then N disappearance should have shown a stronger linear decrease. Decreasing OM digestion in the large intestine was probably the result of increased OM entry into the large intestine with more HMS.

Organic matter disappearance in the large intestine (% of OM intake) tended to decline linearly ($P<.15$) as did ADF disappearance ($P<.10$) with more HMS. Starch digestion in the large intestine (% of starch intake) did not respond to the ratio of DRC:HMS and averaged 4.8% across all diets. The large intestine did not appear to compensate for poor pre-ileal starch digestion to the extent reported by Hibberd et al. (1985) and Streeter et al. (1984) with sorghum grain varieties. Perhaps ruminal starch digestion was extensive enough to limit starch available for fermentation in the large intestine.

Ruminal OM digestion (% of entry) decreased linearly with more HMS. The rumen was the primary site of OM digestion (Figure 22) (59.7% of OM intake). The small intestine was the secondary site of OM digestion (14.5% of OM intake). The large intestine was the tertiary

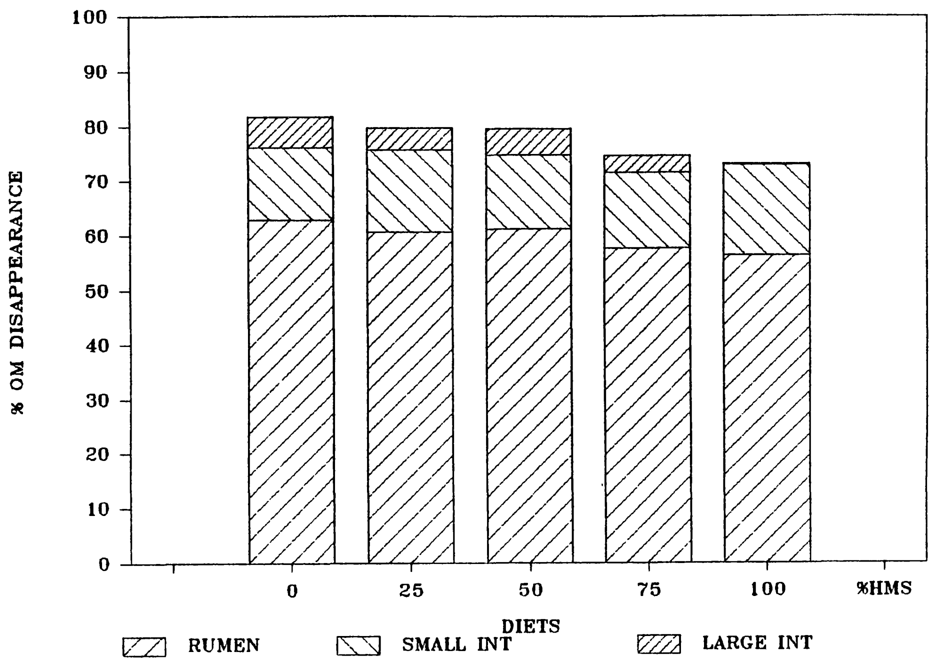

Figure 22. Site and Extent of Organic Matter Digestion

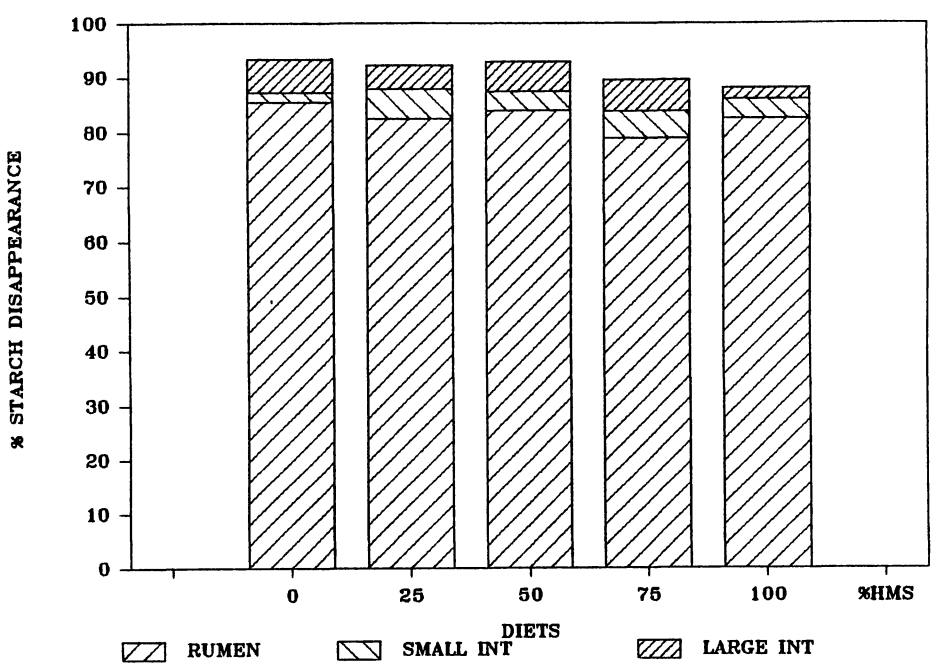

Figure 23. Site and Extent of Starch Digestion

TABLE XIX

EFFECT OF ALTERING THE DRC:HMS RATIO ON NUTRIENT DISAPPEARANCE FROM THE RUMEN, SMALL AND LARGE INTESTINES

	DRC:HMS					
Disappearance	0	25	50	75	100	SE[a]
Rumen (g/day)						
Organic matter (corrected)	4186	4064	4166	4000	3908	138.1
Starch[b]	3542	3371	3476	3316	3709	104.7
Small intestine (g/day)						
Organic matter	792.7	893.1	814.6	837.6	1006.2	117.77
Starch	71.2	220.3	140.1	209.3	161.5	66.18
Total N	83.9	86.4	84.1	81.0	95.2	6.69
Non-ammonia N	79.5	80.1	78.2	74.6	88.4	6.57
Large intestine (g/day)						
Organic matter	339.4	233.7	284.4	185.5	-3.4	133.29
Starch	250.6	178.5	227.4	238.4	93.8	89.67
ADF	39.9	10.4	43.4	-29.1	-51.6	32.28

[a]Standard errors presented for the small and large intestines are for blends 25, 75 and 100. Standard errors for blends 0 and 50 are approximately 20% higher due to missing cells in periods 4 and 5.
[b]Quadratic ($P<.05$).

site of OM digestion (3.6% of OM intake); like the rumen, digestion (% of entry) decreased linearly with more HMS.

The rumen was the major site of starch digestion (Figure 23) (82.7% of starch intake) and appeared to respond to altering the DRC:HMS ratio. However, the amount of starch disappearing in the rumen (g/day) was the observation showing a response to blend rather than ruminal starch digestibility on a percentage basis. In this study, the large and small intestines were minor sites of starch digestion with slightly more starch digestion in the large intestine (4.8% of starch intake) than the small intestine (3.8% of starch intake). The amount of starch that disappeared (Table XIX) from the large intestine (197.7 g/d) also appeared to be greater than from the small intestine (160.5 g/d).

Microbial fermentation occuring in the rumen and large intestine appeared to be much more responsive to the ratio of DRC:HMS than was digestion in the small intestine. Our results suggest that HMS can be included in a blend. However, OM, N and possibly starch digestion begin to decline more dramatically at high levels of HMS (e.g. blends 75 and 100). Further study is needed to precisely determine the extent HMS can be included before nutrient digestibility begins to fall. Performance data is also needed with different DRC:HMS ratios in a blend to determine if performance responds similarly to digestibility.

CHAPTER V

SUMMARY

Four widely divergent sorghum grain varieties were evaluated in experiment 1 to determine the effect of sorghum variety on site and extent of nutrient digestion in beef heifers. The varieties used included: 1133, a waxy bird resistant type; Darset, a normal bird resistant type; Dwarf Redlan, a waxy non-bird resistant type and millrun, a normal non-bird resistant grain. In experiment 2 five blends were used containing different amounts of high moisture harvested sorghum grain and dry rolled corn to determine the effect of altering the ratio of dry rolled corn to high moisture harvested sorghum grain on site and extent of nutrient digestion in beef heifers. The ratios between dry rolled corn and high moisture harvested sorghum grain included: 100%;0%, 75%:25%, 50%:50%, 25%:75% and 0%:100%.

Experiment 1

Total tract nitrogen and non-ammonia nitrogen digestibilities were lower ($P<.01$) for the bird resistant varieties (1133 and Darset). Presumably tannin inhibited extensive N digestion by binding to feed protein and/or digestive enzymes.

Ruminal organic matter and starch digestibilities were not significantly influenced by sorghum variety. Bird resistant varieties (1133 and Darset) appeared to have greater starch digestion in the rumen. Perhaps the microbes can adapt to high tannin levels or tannins may inhibit some less efficient bacterial species competing for starch in the rumen.

Total feed N digestibility in the rumen was much lower ($P<.05$) for bird resistant varieties (1133 and Darset). Ruminal escape of feed nitrogen was greater for bird resistant varieties than for non-bird resistant varieties ($P<.05$). Tannins may have prevented feed N or urea (feed or endogenous) from being degraded in the rumen; thereby, depressing apparent ruminal feed N digestion. Ruminal tannin destruction appeared to be extensive for bird resistant varieties (1133, 72.2% and Darset, 76.1%). True microbial efficiency was not influenced by sorghum variety because of proportionate increases or decreases in both microbial protein production and organic matter truly fermented in the rumen.

Starch digestibility through the ileum tended to be greater ($P<.10$) for waxy, Dwarf Redlan (84.7%) and 1133 (85.0%) than normal, millrun (76.2%) and Darset (81.0%). Waxy starch is probably more available to the digestive process due to the branched nature of amylopectin.

Total ileal N and ileal non-ammonia N digestibilities were lower ($P<.05$) for bird resistant varieties (1133 and Darset). Non-ammonia N digestion in the small intestine tended to be depressed for bird resistant varieties ($P<.15$) with Darset showing greater depression than 1133. Tannin levels are presumably responsible for this depression.

Starch digestion in the small intestine appeared to be higher for waxy varieties. Therefore, the small intestine was a more important site of starch digestion (% of intake digestion) for waxy varieties.

The large intestine tended to be a more important ($P<.15$) site of starch digestion for normal varieties, Darset (8.8%) and millrun(14.2%) than for waxy varieties, 1133 (6.9%) and Dwarf Redlan(6.8%).

This experiment suggests that sorghum grain variety does alter site and extent of nutrient digestion. The primary nutrient affected by variety was N and the bird resistant characteristic seemed to have the greatest influence. Nitrogen flow data might have been easier to interpret if ruminal liquid dilution rate and particulate passage rate had been measured. Starch digestion did tend to be altered by sorghum variety, perhaps at higher levels of feed intake differences may be statistically significant. Waxy grain varieties appear to be better utilized before the ileum ($P<.10$) resulting in less ($P<.15$) starch fermentation in the large intestine.

Experiment 2

Total tract organic matter, non-ammonia N ($P<.05$) and N ($P<.01$) digestibilities decreased linearly as HMS replaced DRC. Starch digestion through the total tract tended to be depressed linearly ($P<.10$) as the level of high moisture harvested sorghum increased in the blend. Perhaps, as Seckinger and Wolf (1973) have suggested, protein encapsulation limited starch availability in HMS.

Ruminal pH suggests that salivary flow may have increased with the inclusion of HMS; thereby, increasing chyme flow ($P<.01$) through the duodenum. Ruminal organic matter digestibility tended to decline in a linear manner ($P<.10$) when the level of HMS was increased resulting in a linear increase in ruminal ammonia concentrations ($P<.10$) with less DRC.

Total feed N and feed non-urea N digestibilities through the rumen tended to respond quadratically ($P<.10$) as HMS was replaced by DRC. Ruminal escape of feed N tended to respond quadratically ($P<.10$) as the HMS to DRC ratio was altered. Ruminal pH may have altered protein solubility and digestibility of DRC and HMS proteins differently.

The efficiency of microbial protein production was increased linearly ($P<.05$) by replacing DRC with HMS. Linearly increasing ($P<.05$) microbial protein production was the primary factor responsible for increased microbial efficiency. Efficiency may have been increased due to increased duodenal chyme flow (Bergen and Yokoyama, 1977).

Nutrient digestibilities in the small intestine (% of entry) were not significantly affected by altering the ratio between DRC and HMS. However, the small intestine as a site of organic matter and N digestion (% of total digestion) appeared to compensate to some degree for incomplete ruminal digestion. Organic matter ($P<.06$) and starch ($P<.05$) digestibilities in the large intestine were decreased linearly by increasing the level of HMS present.

Fermentation appeared to be influenced to a much greater extent by altering the ratio of wet sorghum to dry corn than enzymatic digestion. The moisture level in the blend may be an important factor responsible for altering bacterial fermentation. The acidity of HMS may also stimulate salivary flow; thereby, altering the rumen environment and fermentation. The data may have been easier to understand had ruminal dilution rate and particulate passage rate been measured. Higher levels of feed intake may allow significant differences to be detected in the small intestine. However, it would be difficult to maintain intakes above the 2% of body weight (DM basis) level used in this study.

General Observations

Experiment 1 points out several factors related to sorghum grain varieties that need further study. Waxy grain varieties may offer a method of overcoming some of the adverse nutritional effects of the bird resistant characteristic. Waxy sorghum varieties also appear to have a greater digestibility when the bird resistant characteristic is not present. Bird resistant grains need investigation to determine the metabolic fate of condensed tannins in the ruminant animal and to determine why the bird resistant characteristic reduces nitrogen digestibility. Future work should deal with currently available sorghum hybrids. An attempt should also be made to correlate metabolism studies such as the one reported here with cattle performance data. Speculation about the effects of increasing small intestinal digestion on performance has been great, but a clear relationship has not been demonstrated. Using commercially available sorghum grain hybrids would also generate data useful in accessing current beef cattle NRC (1984) energy values for sorghum grain.

Experiment 2 suggests that high moisture harvested sorghum grain can be blended with dry rolled corn (up to 50%) without suffering a great depression in nutrient digestion. Whether animal performance would also be maintained when the diet contained 50% sorghum is not known. Blending grains of different types and/or different forms should provide a method of reducing the cost of processing (when a portion of the diet is processed) and including grains less desirable than corn in rations without reducing animal performance. Further study involving blends of various combinations is needed in order that digestibility and animal performance may be knowledgeably considered as variables in the selection of grains and/or processing methods for feedlot cattle.

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VITA

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Thesis: SITE AND EXTENT OF DIGESTION IN BEEF HEIFERS: INFLUENCE OF SORGHUM GRAIN VARIETY AND BLENDS OF HIGH MOISTURE SORGHUM AND DRY CORN GRAIN

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Education: Graduated from Winola High School, Viola, Illinois, May, 1978; received Associate of Science Degree from Black Hawk College East Campus, May, 1980; received Bachelor of Science Degree in Animal Science from the University of Wisconsin - River Falls, River Falls, Wisconsin, May, 1982; completed requirements for the Master of Science Degree in Animal Science at Oklahoma State University, December, 1985.

Experience: Born and raised on a farm near New Windsor, Illinois; laborer for Streeter family farm, summers 1972-1982; graduate assistant at Oklahoma State University, 1982-1985.

Membership: American Society of Animal Science, Gamma Sigma Delta.